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Gzowski, Sir Casimir Stanislaus

DESCRIPTION

OF

THE INTERNATIONAL BRIDGE,

CONSTRUCTED OVER

THE NIAGARA RIVER,

NEAR

FORT ERIE, CANADA, AND BUFFALO, U.S. OF AMERICA.

TORONTO:
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1873.

Eng 38.73.3 F

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To the Right Honourable

SIR FREDERICK TEMPLE, EARL OF DUFFERIN, K.T., K.C.B., &c., &c.,

Governor-General of Canada.

My Lord,

When I asked permission to dedicate these pages to you, I was so much impressed with the interest taken by your Lordship in the Works of the International Bridge and their detail, that I did not feel, as I do now, I was presuming upon your good nature, and over-estimating the value of my little book.

The ready and gracious manner in which my request was acceded to, assures me, however, that your Lordship saw no presumption in it. I have, therefore, some pride in inscribing these pages to you, and am convinced that, containing, as they do, an account of a work of some public importance to Canada, they will possess an interest to your Lordship beyond their own merits.

I have the honour to be,
My Lord,
Your Lordship's most obedient Servant,
C. S. GZOWSKI.

Toronto, 30th September, 1873.

PREFACE.

In the construction of the International Bridge, difficulties and obstacles presented themselves which, I believe, rarely if ever occurred together before in any similar work. They were as follows:

Depth of water nearly 50 feet, with frequent, sudden and considerable fluctuations

Rapid and changeable current, varying from five-and-a-half to nearly twelve miles an hour.

Unreliable anchorage.

Exposure of caissons, with all the appliances and plant, to destruction from rafts of unmanageable and enormous dimensions during the entire season of navigation.

Impossibility of carrying on the work during the winter on account of enormous masses of floating ice.

Treacherous bottom.

Limited amount of capital furnished for construction of the work.

Some of these obstacles were quite unexpected; and while, in overcoming all the difficulties, means were used well known to Engineers, in many instances new applications were made of such means, and in others plans entirely novel were designed and executed.

These difficulties, and my intimacy with them, caused me, as they presented themselves, much anxiety.

The contract for building the Bridge having been taken by the firm of which I am a member, all practical operations devolved upon myself; and as the cost of the undertaking was limited in price, much thought was necessarily devoted to overcoming every obstacle economically as well as perfectly.

In the belief that a description of the construction of so important a work cannot but interest the public, and that much may be found in it of practical utility to my own profession, I am induced to publish the following pages.

I must add that the skill, zeal and industry of the Staff connected with the work have been beyond praise. But for them many difficulties which were soon overcome would have proved to be great and serious obstacles; and to their active co-operation I am mainly indebted for the early completion of the Bridge.

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INTERNATIONAL BRIDGE.

CHAPTER I.

HISTORY OF THE BRIDGE.

The first Bridge ever erected to carry Railway trains across the waters dividing Canada and the United States, was the great Suspension Bridge, about two miles below Niagara Falls. This Bridge was completed and opened for Railway traffic in the year 1854. It connected the Great Western Railway, then running to the Niagara frontier, with the New York Central Railroad to Boston and New York.

The completion of that Bridge gave a great impetus to the consideration of the question of bridging navigable waters on the American continent; and railway bridges have since been constructed across the Hudson River at Albany, and at several points both across the Mississippi and Missouri Rivers. It gave birth also to the idea of the great International Bridge at Buffalo, now completed, which was designed to facilitate intercommunication between the Railways of Canada and the United States at the important City of Buffalo.

Charters for the construction of this work were passed in the year 1857, by the Parliament of Canada, and by the Legislature of the State of New York.

They were obtained by the Railway interests upon the two sides of the River, and were intended to connect the system of Railways then being constructed in Canada—converging at Fort Erie, at the eastern extremity of Lake Erie—with the Railways through the State of New York centreing in the City of Buffalo.

These Charters lay dormant for several years, owing to the impossibility of securing the funds necessary for the construction of so great a work.

The New York Central Railroad, which has one of its termini at Buffalo, secured a connection, upon the south shore of Lake Erie, with the Lake Shore Railroad running through to Chicago. It had also, by the Suspension Bridge already named, a direct connection with the Railway system of Canada, extending from Clifton to Windsor, opposite Detroit.

The parties first interested, in Canada, in the construction of the Buffalo Bridge, were connected with the Buffalo, Brantford and Goderich Railway, a line starting from Fort Erie, and running across the peninsula of Upper Canada to Goderich upon Lake Huron. This was, however, for many years a weak Corporation, and became ultimately bankrupt, necessitating the reorganization of its affairs, which finally passed into the hands of a new Company—the title being changed from its original one of "Buffalo' Brantford and Goderich Railway," to "Buffalo and Lake Huron Railway."

This latter Company was owned almost entirely in England. Considerable sums were advanced for the completion of the line, so that it was at length finished, from Fort Erie to Goderich, crossing in its course the Great Western Railway at Paris, and the Grand Trunk Railway at Stratford. By these means it obtained a connection with the West; but although strenuous efforts were made by its friends, they were unable to raise the necessary funds for the construction of the Bridge.

The Railways centreing at Buffalo, although greatly desiring the completion of the work, failed, from various causes, to lend that material assistance which was indispensable. Various plans were from time to time proposed to obtain municipal aid from the City of Buffalo, and Acts were passed by the Legislature of the State of New York, in the year 1858, authorizing the City, upon certain conditions, to guarantee interest upon a portion of the Capital Stock of the International Bridge Company; but this, after much negotiation, was never carried into operation.

Matters remained in this state for several years. The Buffalo and Lake Huron Company, like its predecessors, fell into financial difficulties, and for several years the control of it was competed for by the Great Western and Grand Trunk Companies. Ultimately an agreement was made between the Buffalo and Lake Huron and Grand Trunk Companies, by which the latter took a lease of the Buffalo and Lake Huron line, acquiring the entire control of the property for a specified rental.

These arrangements being concluded, vigorous efforts were again made to revive the scheme for constructing the International Bridge, but which were not successful for several years.

At length the agreements between the Grand Trunk and Buffalo and Lake Huron Companies were reduced to a practical and simple condition, and the whole sanctioned by the Parliament of the Dominion of Canada. Upon these arrangements being completed, and the Grand Trunk Company authorized by Parliament to guarantee interest upon the cost of the Bridge to the extent of £20,000 sterling per annum, the Capital for its construction was at length raised in England in the year 1870.

The total amount of Capital thus raised amounted to . .	£272,500
The amount of Bonds being	205,700
And of Preference Share Capital	66,800

By Acts passed by the Parliament of Canada, and by the Legislature of the State of New York, the two Companies, which had been Incorporated by those Legislatures, were authorized to amalgamate and form one Company, under the title of "The International Bridge Company," with a nominal Capital of $1,500,000. They were authorized, in the same way, to issue Bonds to the extent of $1,000,000.

The issue of the Securities before mentioned was successfully carried out at a net price of rather more than 90.

As soon as these financial arrangements had been completed, a Contract was let by the International Bridge Company, with the concurrence of the Grand Trunk Railway Company, to Messrs. C. S. Gzowski and D. L. Macpherson, of Toronto. The Contract was for the completion of the Bridge from the Canada shore at Fort Erie, to the American shore at Black Rock, and was for the sum of $1,000,000. The Contract required that the Bridge should be constructed with stone piers and iron superstructure, with the Draw-bridges in the main river and across the artificial navigation at Black Rock in such a manner as might be required by the proper authorities. It should here be stated that in order to avoid all question of interference between the rights of Great Britain and the United States—the territories of which the Niagara River divides—the Act passed by the Parliament of Canada authorizing the construction of the Bridge was reserved for Her Majesty's assent, which was given after the whole matter had been fully investigated by the Imperial authorities. In like manner, in order to give full legality to the authority granted by the State of New York, an Act of Congress was passed at Washington, by which the United States Government agreed to the construction of the Bridge, and declared it to be a post route of the United States.

This Act required that the Bridge, in regard to its form of construction and the size and position of the Draw-bridges, should be subject to the approval of a Board of United States Military Engineers, who were instructed to examine into the question, and the plans proposed for the Bridge were in due course submitted to their consideration.

They made various suggestions in regard to the position of the Draw-bridges, which were adopted, and the Bridge is now completed in accordance with their views, and under the instructions which their Report contained. These changes involved certain departures from the original Contract. They altered the position of the Draw in the main river, and to a certain extent added to the cost of constructing the work.

The Draw-bridge in the main river is a double one, worked upon a pivot or centre pier, the whole length of the Draw being 362 feet, giving two openings on each side of the pivot pier of 160 feet.

The Draw-bridge across the artificial navigation of Black Rock Harbour was settled by the Commissioners for the Erie Canal, which navigation forms the outlet of the canal into Buffalo, and the Draw-bridge here consists of a Bridge worked from a centre or pivot pier with two openings on each side of the pivot of 90 feet each.

The same Contractors also took the contract for completing the works necessary to connect the Bridge with the New York Central Railway at Black Rock Harbour, and also about 3½ miles of railway from the Canada end of the Bridge to form a connection with the main line of the Buffalo and Lake Huron line. The contract did not include engineering expenses or the necessary land to be acquired for the construction of the works.

Upon these preliminary arrangements being made, the necessary engineering staff was appointed: the Engineer-in-Chief being Mr. E. P. Hannaford, the Engineer of the Grand Trunk Railway, who had for his resident Engineer, Mr. Joseph Hobson, (who has resided continuously upon the spot) with the necessary staff of assistants.

The length of the Bridge from the abutment on the Canada shore to the abutment on Squaw Island, which lies between the main river and Black Rock, is 1,967½ feet. The distance across Squaw Island is 1,167 feet, and from the abutment on Squaw Island to the abutment on the main shore on the American side is 517 feet, making the total length of the Bridge 3,651½ feet.

A full description of the Bridge and works will be found in the following pages, but it may be well to give here a brief general outline.

From the abutment on the Canada shore, the Bridge is carried by six piers to the end of the main Draw. The first three spans are of 197 feet each, and the next three 248 feet each. The Draw-bridge rests upon a pivot pier, which is No. 7, and the eastern end of the Draw rests upon the last pier in the river, which is No. 8. From that pier to the abutment on Squaw Island is a span of 197 feet.

The depth of water at each of these piers is as follows:

No. 1.	10 feet.
2.	20 "
3.	33 "
4.	47 "
5.	48 "
6.	30 "
7.	16 "
8.	9 "

It is not necessary to describe here the mode of constructing the caissons on which the piers are built, but it is safe to say that the plan adopted is a novel one in engineering works, and displays great skill on the part of the Engineers who designed and executed it. Across Squaw Island the Bridge is carried at present by a line of trestle work twenty feet high, which is to be filled in from a cutting on the Canada shore, but which could not be done until the Bridge enabled trains to take the material to the spot where it was to be deposited. It is intended to widen considerably the present structure across Squaw Island as it is filled in with earth, so as to give room for three or four lines of rails between the two Bridges, which will add materially to the amount of traffic which can be passed from one side of the river to the other. The Draw-bridges across the main river and the canal are both worked by steam power, and the large Draw, 364 feet in length, can be opened or shut in rather less than 60 seconds.

The current in the river, which added very largely to the difficulty of executing the work, runs on an average about 5½ miles an hour, and under the influence of a strong southerly wind blowing down Lake Erie, will run as fast as 12 miles an hour.

In order to prevent the possibility of any damage arising either to the Bridge or to vessels navigating the river owing to the strength of this current, the law requires that a Steam Tug be always maintained during the season of navigation by the Bridge Company, to aid vessels and rafts in passing through the Draw.

Considerable discussion arose during the construction of these works from their novelty, and from the peculiar conditions under which they had to be executed, in regard to the stability of the structure. The first three piers, from the Canada side, have now been down during three winters,—in two of which the ice has been heavier and stronger than had been known for many previous years, and far above the average. Four of the other piers, including those in the deepest water, and where the greatest strain caused by the direction of the current will come upon them from ice, have been down throughout last winter, which, for severity of cold and strength of ice, was much above the average. It is, therefore, satisfactory to be able to say that the piers, which had to encounter these exceptionally severe winters and runs of ice, have shown not the smallest settlement or injury, and have proved beyond all doubt the perfect stability of the works, and their capacity to bear any strain that, under any circumstances, can ever be placed upon them. In point of fact, their strength is greatly in excess of that usually required in works of this kind. They have been well designed and executed, and in every respect form a work of the very best class. There are always persons who, in a work of any magnitude, are ready to give expression to fears and doubts as to its stability and strength.

This, of course, is more commonly the case in matters where the novelty of the work and peculiarity of position are out of the usual course of things, as these conditions afford the greatest latitude to those who are always ready to find fault, who are, as a rule, excellent critics, however inefficient they may be as authors or designers. The great Victoria Bridge at Montreal, built under the direction of the late Robert Stephenson, was condemned in advance by persons of the class referred to, as being incapable of withstanding the strain to which the runs of ice would subject it. The critics in that case, like those in that of the International Bridge at Buffalo, have been sternly rebuked by the inexorable logic of events, which affords another proof, if any were wanting, of the facility with which people can find fault.

The iron superstructure of this Bridge has been constructed at the extensive Iron Works at Phœnixville, Pennsylvania. It is known as the "Pratt" or quadrangular truss, and is of a kind being very generally adopted in the United States and Canada. The two large Bridges on the Intercolonial Railway in Canada, across the Restigouche and Miramichi Rivers, are being constructed by the same firm, and on the same plan. Every part of the material employed in the construction of this Bridge was subjected, at the Phœnixville Works, to the severest tests before being allowed to form part of the superstructure. The quality of the iron is unmistakably equal to that of any iron to be found in the world, and the workmanship in every part has been subjected to most careful inspection, and is of the very highest quality. The appearance of the Bridge is exceedingly light and graceful. It derives its great strength from the depths of the truss, and presents no great surface to the wind, as is the case with the Victoria Bridge at Montreal.

Since the first Acts were passed authorising the construction of the Bridge, the Railway system both of Canada and the United States has rapidly grown, and in consequence there will be a very large traffic indeed over the Bridge. On the American side both the New York Central and New York and Erie Railroads have one of their termini at Buffalo, and both will have a connection with the Bridge.

There are Railways also now running from Buffalo to Philadelphia, Baltimore, and into the Iron and Coal Districts of Pennsylvania and Ohio.

On the Canada side of this Bridge will be the only outlet across the Niagara frontier for the traffic of the Grand Trunk Railway, which extends through the whole of Western Canada, and has one of its termini at Detroit. It connects at that city with the Michigan Central Railway, thus forming a direct connection between Buffalo and Chicago, and the vast Western country which has Railway communication with that great centre. During the season of navigation lines of Propellers run at Sarnia in connection with the Grand Trunk Railway to and from Chicago, Milwaukee, Green

Bay, Mackinac, Sault Ste. Marie, Duluth, Fort William, &c. This route cuts off the great detour formed by the Detroit River and Lake Erie, and these vessels will pour into Sarnia vast quantities of produce for transport across the neck of country and the Bridge, to Buffalo.

The Great Western Railway — seeing the great Railway centre now forming at Buffalo, and in order to relieve the strain upon its own Suspension Bridge, which is taxed nearly to its utmost capacity — are building, and have nearly completed, a duplication of their line from Glencoe to the International Bridge, and will thus send over the Bridge a very considerable portion of the large business now passing over the Great Western Railway.

A third line of railway through the peninsula of Upper Canada, the Canada Southern Railway, which runs from Amherstburg to Fort Erie, has been under construction during the last two years, and is now completed, waiting to send its traffic also over the International Bridge.

At Amherstburg that Railway will cross the Detroit River by means of a ferry, forming a connection with the Toledo, Wabash and Western Railway, and, it is also understood, will form connections with Railways running to Chicago, so securing a large traffic, the eastern outlet for which can only be over the International Bridge. On both sides of the River, therefore, there are now converging several thousand miles of Railway, which will find this Bridge the main, if not the only, outlet for their traffic. There seems no reason to doubt, therefore, that the capacity of the Bridge will be fully tested by the amount of traffic that is to pass over it, which, from the stability of its works and the speed at which trains can run, will be very large. The cost of the Bridge, including the connections with the New York Central Railroad, and with the main line of the Grand Trunk Railway, including all the extra outlay occasioned by the difficulties in the foundation of some of the piers, and the changes recommended by the United States Engineers, adding also Interest upon the outlay during construction, will not quite reach the sum of $1,500,000, or about £300,000 sterling.

There are few, if any, works of the same magnitude, constructed of the same permanent materials, and executed under such great difficulties, which have been completed at so small a cost.

For the mode and details in which that construction has been carried on, the reader is referred to the pages which follow.

CHAPTER II.

CHARACTERISTICS OF NIAGARA RIVER AND LOCATION OF THE BRIDGE.

While the advantages that would accrue from a Bridge across the Niagara River near Buffalo were obvious, the practicability of the proposal to erect one was by no means so apparent.

The difficulties to be overcome in building a permanent and rigid structure across the River were so great, that the project was viewed, even by the boldest, with some degree of distrust. The facts, arguments, and conjectures of the advocates of the scheme were certainly not devoid of plausibility, but at the same time there hung over it an element of extreme uncertainty, which only the actual success of the work has been able fully to dispel.

It is true, the Niagara River is free from some of the peculiarities of the Missouri and Mississippi Rivers, which have rendered the work of bridging them memorable triumphs of engineering skill. It has not the moving sands, the unstable bottom, the ever-changing channel, and the periodically high floods which are among the characteristics of those Rivers. It has, however, difficulties which are peculiarly formidable, and which sufficiently warranted the doubt of the proposition to cross it with a permanent structure.

The great depth of water, the force of the current, and the ice runs, which were believed by those best acquainted with the River to be almost, if not altogether, irresistible, with the sudden rises of water,—which, although not of great height and duration, are as dangerous and destructive in some respects as the freshets in many other Rivers—presented obstacles of no light character to the successful erection of a Bridge.

The Niagara River being of short length, and a strait connecting link between Lakes Erie and Ontario, the elevation of its surface and the fluctuations in the height of the River are coincident with those in Lake Erie, which, leaving out of consideration the sudden rises and falls caused by storms, &c., do not vary more than two feet.

The general level of the River being, therefore, nearly permanent, there is very little danger of the *regimen* of the stream being disturbed, even were its bed much looser and more easily moved than it is. But when it was ascertained that the portion of the bed of the River which is not rock consists of a heavy clay, with a light covering of gravel over it, the probability of danger from any serious scour was considered to be reduced to an almost infinitesimal extent, as all that could happen would be the removal by the current of the gravel overlaying the clay which is too compact to be at all affected by it. In fact, the permanent character of the River bed and banks was one of the few favourable features that brought the scheme of bridging the River, at this point, within the bounds of probability.

Although the unalterable nature of the channel and bed of the Niagara River gave assurance of the permanence of any structure thrown across it, so far as stability depends upon good foundations and unyielding banks, yet the accidental disturbances to which the water in the River at the Bridge site is subject, in consequence of its proximity to Lake Erie, are of such a description, that the actual construction of the Bridge had to be carried on in the face of constantly recurring difficulties; while, as already stated, the general elevation of the water, extending over long periods, is not great, the occasional rises, lasting for a few hours, are sudden and of great violence.

A heavy north-east wind causes the River to fall nearly two feet in the course of less than half a day, by forcing the water from the entrance of the River back into the Lake; on the other hand, a south-west gale, by bringing the whole "fetch" of the Lake to bear upon its outlet, has the effect of raising, occasionally, the water at the Bridge from four to five feet above its ordinary level in less than as many hours. Such a rise taking place increases the surface inclination of the River and accelerates the current, which at times has been known to attain at the Bridge site a speed not less than twelve miles an hour.

Although the sudden rises in the surface of the River are invariably caused by winds blowing down the Lake, it is noticed as a curious circumstance, that the water generally rises a little in advance of the wind; that is to say, before the wind, which is producing the increased height of water, actually reaches the east end of Lake Erie.

The normal velocity of the water is high, as the surface inclination of the River between Lake Erie and the head of the Rapids above Niagara Falls—a distance of nineteen miles nearly—is fifteen feet. The inclination is not, however, uniform, the steepest part of it being between the entrance of the River and the head of Grand Island, embracing the Bridge site. The depth of the River between these two limits is extremely irregular, varying from about eighteen feet to nearly forty-five.

The River bed is known to be solid rock above Squaw Island; along side of the Island it consists partly of rock and partly of clay, with a thin covering of gravel above the clay. Below Squaw Island no examinations were made by the Bridge Staff to discover the nature of the bottom, but it is well known to be of the same irregular and composite character as above.

The banks of the River above the Falls are low, except in front of Buffalo on the American side and near the Falls on the Canadian side. They rarely exceed fifteen or twenty feet in height, and are composed of clay, with occasional exposures of rock.

It may be well to explain that in front of Buffalo, and, in fact, all the way to Tonawanda, the east bank of the Erie Canal is considered to be the east bank of the River, as the Canal is formed by taking in or enclosing, part of the River, by means of a mole or breakwater. By reason of the changes which were made when forming the Canal, the west side of Squaw Island, which is about a mile long, is now the east side of the River, and that part of the River which passed to the east of Squaw Island is now Black Rock Harbour. Squaw Island is itself low, the greater part of it being a marsh scarcely raised above the usual surface of the River, and nearly wholly submerged when the water is high.

During construction, the depth of water, velocity of current, unequal foundations, with the risks inseparable from the passing of rafts and vessels, were expected to be the chief difficulties to be encountered; while the greatest danger it was anticipated, to which the Bridge, after it was built, would be exposed to, would be from ice fields which are carried down the River from the Lake.

The River never freezes all the way across, the rapidity of the current prevents this; but generally about the middle of November the ice begins to form along the shores of the Lake, and a few cold nights are almost sufficient to fill the River with small cakes broken off from the ice thus formed.

These cakes are worn by friction against each other till they are nearly round and are about a foot in diameter. If the weather remains cold, these pieces become frozen together into large sheets, which continue to pass down the River until the ice "takes" or sets in the Lake. The River then becomes clear, and remains so until perhaps about the end of February or beginning of March. Sometimes it is free from ice until the end of March or beginning of April; this was the case in 1873. Occasionally, however, heavy runs occur early in the winter. The heaviest happened during the first year the Bridge was being built — it was on the first of January, 1871,—when the ice came down in unbroken fields the full width of the River, but not exceeding fourteen inches in thickness. None of the ice that winter was as thick as that formed during the two following ones, which were of almost unexampled severity.

The ice that comes down before March, unless the season is exceptionally cold, is always extremely hard, and therefore much more likely to be destructive than what passes towards Spring, which has been honeycombed by the sun and rain.

In the winters of 1871-2 and 1872-3 ice of uncommon thickness was formed, and in the former winter fields of it—several times in the months of January and February, (1872)—broke off from the mass in the Lake, passing down the full width of the River, and from half a mile to a mile long. The thickness of these fields was about three feet, and the ice comprising them extremely hard.

Ice runs of this kind gave an excellent idea of the forces against which the piers would have to contend.

Generally the River is free from ice about the beginning or middle of April, but sometimes not until much later. In 1871 the last piece of ice disappeared on the 11th of April; in 1872 there was ice in the River on the 23rd of May, but for some days previously there had not been enough of it to retard or prevent the movements of barges; in 1873 the ice remained until the 13th of May.

Almost invariably the Lake opposite Buffalo, and for miles westward up the Lake, is either frozen or jammed full of ice from the American to the Canadian shores; all the ice that goes down the River being formed along the shores and at the east end of Lake Erie.

Occasionally during the winter large fields will break off and pass down the River, as already stated; but if the weather is steady and severe, the ice in the Lake will probably remain undisturbed until the beginning of March, or even later. When the ice is breaking up, if the direction of the winds is continuously westerly, the only means of escape for the ice is down the River; the opening of navigation in such a case is necessarily late, as many weeks are required to carry off the large quantities of ice accumulated at and near the mouth of the River. If, on the other hand, easterly or north-easterly winds prevail in the spring, the ice is forced back into the Lake, and is dispersed sometimes in very few days.

When high winds prevail in the months of January, February, and the beginning of March, portions of ice are apt to be broken up and piled together in large masses. The pieces composing these freeze together, and form homogeneous masses called "clampers," which are often so thick that they ground in water twenty and twenty-five feet deep. These "clampers," and the large ice fields which enter the River from the Lake, would, it was confidently asserted by men who were supposed to know the River well, endanger the piers. Some even went so far as to state most positively that no pier could be built to resist them; others took the ground that the design of the piers was defective, and that the safety of the Bridge could only be insured by changing their form.

So widespread and so persistent were the clamours of these alarmists, that they reached the ears of bondholders in England, who determined to send out Captain

Tyler, an eminent English Engineer and Inspector of Railways for the Board of Trade in Britain, for the purpose of reporting upon this subject.

He came out to Canada near the end of 1871, and made a very careful inspection of the piers built the previous year; he obtained, also from most trustworthy sources, evidence in reference to the ice flows and other characteristics of the Niagara River. His own personal observations, with the information he obtained from others, fully satisfied him that there were no grounds for alarm. He therefore reported as follows:—

"I have made particular inquiry into the thickness and force of the ice which these piers will have to resist, and have visited numerous other structures exposed to the action of ice under various circumstances, and I have come to the conclusion that the cut waters of the three piers now erected are calculated, when shod with iron, with the slope on which they are constructed of ½ to 1, to cut through and to resist, without danger of failure, any ice which can come in contact with them." Captain Tyler's opinion has proved to be perfectly correct, as the piers have since then been exposed to the ice of two winters of almost unprecedented severity without exhibiting any indication of failure.

Anyone who has been connected with engineering works of a novel character and of considerable magnitude, will most likely concur in the statement, that there will always be found in the vicinity of these works individuals who, instead of drawing inferences from systematic and carefully taken observations, give full play to a fertile imagination, and become "Prophets of evil;" "Job's comforters;" "Birds of evil omen."

The International Bridge would have never been begun had a fraction of the stories about terrible ice runs been credited.

A careful consideration of the subject having satisfied the projectors of the Bridge of its feasibility, it became next a matter of some consequence to select the best site for it.

The location believed to combine the greatest number of advantages, and which was therefore adopted, is about two thousand feet above the lower end of Squaw Island. The width of the Niagara River at that point is about eighteen hundred feet, of Squaw Island about thirteen hundred feet, and of Black Rock Harbour four hundred and seven feet. By going further up the River—above Squaw Island—a shorter crossing could have been obtained with a much less depth of water, but this was more than counterbalanced by the disadvantages. First, of the greater velocity of current, which would not only have added very much to the difficulty of building the piers, but would also have greatly increased the dangers to the passage of rafts and navigation generally.

With a normal current of from seven to eight miles an hour, there would have been great risk in passing vessels, and particularly rafts, through the draw openings, as it is impossible to keep the long rafts straight that are run down the Niagara River to Tonawanda, when they are in that portion of the River between the Black Rock and the entrance to the River.

Second, of the bad anchorage which extends all the way from Black Rock Ferry to near the entrance to Buffalo Harbour. In the event of a sailing vessel failing to make the entrance to the Harbour, and coming within the influence of the current in the River, it could not be brought to anchor in time to avoid a collision with the Bridge.

When the late Mr. A. M. Ross, the Engineer of the Victoria Bridge at Montreal, proposed, in the early days of the Buffalo and Lake Huron Railway Company, to locate the International Bridge near the Buffalo Water Works, so sensible was he of the dangers of vessels drifting against the structure, that he suggested, as part of his scheme, that the entrance to Buffalo Harbour should be moved some distance to the south of its present position, so that vessels entering it might not be exposed to the danger of being drawn into the Niagara River; and he deemed this danger to be of sufficient magnitude to justify the Bridge Company in devoting part of their capital towards making the contemplated change in the Harbour. A third objection to a location above Squaw Island is the costly approach on the east side of the River, and the difficulty of making connections with the Railways terminating in Buffalo. It would have been necessary either to tunnel under the city, or to have made a deep and very long excavation through valuable property. In either case the cost of this approach alone would probably have exceeded the whole expenditure on the Bridge proper.

The drawbacks to a location below Squaw Island were, the great width of the River, the increased length of (loop line) Railway which would have to be constructed to join the Bridge with the Grand Trunk Railway, and the distance of the structure from the City of Buffalo. The last objection might not have carried much weight, had the Bridge been only intended to connect the American and Canadian lines of Railways.

Another reason which had some weight in causing any location between Squaw Island and Grand Island to be rejected was, that as the water was shallow, there would be considerable danger of the piers causing the ice to gorge and form a dam across the River. Although this consideration had its influence in determining the site of the Bridge, sufficient importance was not probably attached to it at the time.

There can be very little doubt that the danger apprehended was not an imaginary one. The evil consequences arising from the placing of obstructions in comparatively shallow water in Rivers which carry down large bodies of ice, were strikingly exemplified in the terrible and disastrous ice gorge which was formed in the Susquehanna River, near its mouth, in the beginning of February, 1873. This accumulation of ice was caused by a number of piers, which were built near the head of Watson's Island for the purpose of intercepting and keeping back timber. Great risk was unquestionably avoided, and possibly great calamity averted, by locating the International Bridge in deep water. That an ice gorge in the Niagara River is by no means an impossibility was shewn a number of years ago, when a dam was formed in the shallow water near the mouth of the River. This dam kept back the water for several hours, and lowered the surface of the River so much that a large part of the bed of the Rapids above Niagara Falls was dry, enabling people to walk out for a considerable distance from the shores. So little water was there running that timber lodged against the rocks and was drawn ashore from near mid-channel above the Falls, a place which, in ordinary stages of the water, is absolutely inaccessible. The considerations enumerated above confined the choice of location within the narrow limits between the head and foot of Squaw Island. Between these points there could be no difficulty in determining the proper place for the Bridge; in fact, the advantages possessed by the site selected were so obvious that they could scarcely be overlooked. They were briefly these:

First. The River and Black Rock Harbour are narrower at the present site of the Bridge than they are anywhere else between the upper and lower ends of Squaw Island.

Second. The water being deep, the current is less rapid. The great depth of water, taken *per se*, is certainly objectionable, but it is less so than a violent current.

Third. The depth of water is so great, that it is confidently believed no danger exists of the ice gorging all the way across the River.

Fourth. The bottom of the River affords good holding ground for anchors for more than half a mile above the Bridge, so that in the event of an accident to a vessel it can, in all probability, be brought safely to anchor before reaching the Bridge.

Fifth. The approach upon the Canada side of the River is good, that upon the American shore is not only an excellent one from an engineering point of view, but is a favourable one, in so far that it destroys very little valuable property, and can easily be connected with the Railway lines terminating in Buffalo.

In locating the Bridge the interests of navigation were kept in view; but so far as they were concerned, it made very little difference where the Bridge was built so long as it was kept out of the swift current above Black Rock Ferry. The Bridge wherever placed must interfere to some extent with navigation, and it was simply absurd to cry out, as many did, that the rights of shipowners must not be trenched upon in the smallest degree. The erection of a Bridge across a navigable stream is always to be deprecated if there be any reasonable way of avoiding it. But if the commercial interests which are to be served by a Bridge are greater than those which are affected injuriously by its erection, there can be no question that the latter must to some extent give way.

In the case of the International Bridge, there cannot be a question as to the superior importance and value of the interests to be served by it, as compared with those of the navigation on the Niagara River.

Although the ground to be traversed by the lines of Railway connecting the International Bridge and the Grand Trunk Railway on the Canadian side of the River, and the New York Central Railway on the American side, had not actually been surveyed previously to the site of the Bridge being chosen, a *reconnaissance* had been made of it, from which it was known that there would be no difficulties whatever of an engineering character in forming the connections. When the connecting lines were located, the length of Railway required to join the Bridge and the Grand Trunk Railway was found to be 3½ miles.

This line was a favourable one, with a good approach to the Bridge, on a tangent with an inclination towards the River of only 15 feet per mile. On the American side two connections were needed with the New York Central Railway; the aggregate length of these was nearly half a mile. One of them was to join with the New York Central Junction Railway, running round the City of Buffalo and into the Station on Exchange Street. The other was to connect with the Niagara Falls Branch of the New York Central Railway, terminating at the Erie Street Station.

The line across Squaw Island, connecting the Bridge across the River with the Bridge over Black Rock Harbour, was on a curve described with a radius of 1,910 feet. The distance between the Bridges measured on this curve was 1,166 feet.

In addition to the connections with the Grand Trunk and New York Central Railways, for which provision was made by the International Bridge Company, junctions were formed with other Railways built since the Bridge works were begun. On the Canadian side of the River two new Railways were run directly to the Bridge, and are now finished,—the Great Western Air Line from Glencoe, the Canada Southern Railway from Amherstburg on the Detroit River and Courtwright on the St. Clair River. Both of these lines are first class roads, built with easy curves and low gradients, intended for American through travel principally, and will therefore bring a vast accession of business to the Bridge.

On the American side of the River the New-York, West Shore and Chicago Railway has been located, and is partly built.

The alignment and gradients of this Railway are such as to warrant the expectation that it will rank, when completed, with the best roads on the Continent, and that it will do its full share towards preventing any block, at Buffalo, of eastward bound traffic brought over the Bridge by the roads on the Canada side. After the choice of location was made, steps were taken to ascertain the direction and velocity of the current, so that the piers might be built exactly in line with it. As no vessels navigating the Niagara River draw more than 12 feet of water, it was considered that information upon the direction and velocity of the current down to this depth would be all that was necessary.

The method pursued to ascertain this was so simple, and at the same time answered the purpose so well, that it is considered worth while to give a detailed description of it. Although the primary object in view was to obtain the direction of the stream, the same operation determined accurately its velocity. The application of the method to ascertain the velocities, &c., at the International Bridge, was proposed by a Board of Military Engineers, who were appointed to examine and report upon the Bridge site and plans by the United States Secretary of War.

The method was briefly as follows:—A base line 1,621 feet long, extending from a point 169 feet above the Bridge, was measured on the west bank of the River. At each end of this base line a theodolite was placed, and two observers were stationed, one to use the instrument, the other to mark time and give signals. At intervals of half a minute of time the angles contained by the base line, and by lines drawn from each end of it to a float in the River, were read simultaneously.

It will be apparent that the positions of the floats taken in this way at the end of each half minute, will not only indicate the direction of the space traversed by the float in the time but will also give its exact length, from which the velocity of the current in miles per hour may be deduced. To distribute the floats a small Tug was used. The Tug went some distance above the upper end of the base line, and when throwing a float overboard whistled to call the attention of those stationed at the instruments at each end of the base line, who continued to take the simultaneous observations upon it until the float had passed below the lines of the Bridge. Observations in eleven lines were taken in this way. These lines were intended to be equidistant, but it was clearly impossible to make them so without determining trigonometrically, or by some other equally troublesome mode, the position of the Tug before throwing out each float. This was not considered of sufficient importance to justify the trouble and loss of time. An assistant on the Tug estimated as nearly as practicable the proper distances from the shore at which the floats were to be thrown in. The floats were pine scantlings three inches by four inches, and were twelve feet long; each was loaded at one end, so that when put into the water it would float in a vertical position, and would show the other end just above the water. To enable the observers on shore to follow these floats easily with their eye, a small staff about eighteen inches long, with a red flag attached, was inserted into the top of each float. No difficulty was experienced in taking the observations, as it was found that an angle could be read and recorded in fifteen seconds, which allowed an equal time for turning the limbs of the instruments and for bringing the cross hairs of the telescopes on to the red flag on the float again.

The positions of the floats at the end of each half minute, taken in the manner above described, were platted to a very large scale, and the direction and velocity of the current in each line were obtained graphically. Figure 3 on plate No. 111 shews this diagram drawn to a reduced scale.

No real difficulty was involved in the taking of the velocities and directions of current as above described, nothing more being required when doing the work than constant attention; but the next operation to be described, that of taking soundings, was one of the most troublesome connected with the Bridge survey. The first attempt made in a small boat, proved to be a failure. The next plan tried was to anchor a Tug over the site of each pier and sound all round it from the deck. This was only partially successful, as, by reason of the swiftness of the current, the lead was carried a long way down the River before it touched the bottom, and the depths obtained in this way were consequently too great, as the figures on the lead line represented the hypothenuse of a right-angled triangle instead of the perpendicular.

The next plan followed was to erect on a scow a framework to carry an iron rod one inch and a quarter diameter, working vertically through guide rings. It was thought that the rod if allowed to fall suddenly would reach the bottom without being deflected from an upright position: but even this did not answer, as upon the first trial the current bent the rod so much that it could not be used again. The method finally adopted, and which succeeded perfectly, was to anchor a large barge or scow so that the centre line of the Bridge passed over it at midships. Across the barge timbers ten feet apart were laid, with their ends projecting twenty feet beyond one side of it. The barge was then placed and retained in such a position, by means of a side anchor, that the projecting ends of the cross timbers were on a line nine and a half feet beyond the outside of the ground the pier would cover. When the barge had been properly placed, a Tug, kept in attendance during the whole time the soundings were being taken, towed a yawl with a suitable crew three or four hundred feet above the barge. The yawl was then cut adrift and allowed to float down the River, being steered so as to pass exactly under the ends of the projecting timbers. So soon as the yawl was detached from the Tug, the person whose duty it was to take the soundings threw the lead overboard and allowed it to remain suspended from the boat and at a distance of one or two feet from the bottom of the River.

It will be seen that by allowing the lead to hang in this way from a boat which was drifting down the stream it would hang perpendicularly under the boat, as both it and the boat would have the same velocity—the velocity of the current. The water would certainly move with somewhat less rapidity near the bottom of the River than at the surface, but the weight of the lead was in all cases sufficient to overcome the difference, and to maintain the lead line in as nearly as possible a vertical position. As the yawl drifted under the end of the first timber the man with the lead dropped it the required distance, one or two feet as the case might be, touched bottom and called out the reading, which was recorded by an assistant upon a diagram previously prepared. Probably before the man with the lead line could recover himself and be ready for another sounding, the boat had drifted under say the last timber, when he again took the depth. The Tug was always in readiness to tow the yawl after passing the barge up the River again. By repeating the operation described above, perhaps three or four times in each line, a sounding was obtained under the end of each timber. When the soundings on one line were finished the barge was moved nine and a half feet over, and soundings again taken in the same way as before, and so on until five lines were gone over, covering a space of eighty feet long by thirty-eight feet wide. The scow scour for every line of soundings was accurately placed in accordance with signals given from the end of a base line on the Canada shore, by an observer with a theodolite. The soundings taken in the way described proved to be remarkably correct, and at no time during the progress of the works was any trouble experienced or expense incurred in consequence of any error in them.

The depths of water in which the piers would have to be built was found to be least at No. 8, where it was only about seven feet, and to be greatest at No. 5, where it was found to be forty-three feet; this last depth was afterwards increased several feet by the removal of gravel from the site of the pier.

The velocities of the current and the soundings thus obtained, together with the width of the River, afforded sufficient data for arriving at a moderately close approximation to the quantity of water discharged by the Niagara River in its normal state.

The area of the section of the River at the Bridge site was in round numbers as nearly as possible 41,000 square feet, and the average velocity of the water per second six feet. The discharge therefore would be 246,000 cubic feet per second, or say 1,535,040 imperial gallons.

The discharge, however, frequently differed materially from this, the variations being caused by the fluctuations in the height of the surface of the River produced by winds and ice. A record of these fluctuations was kept daily from the 1st of August, 1870, to the 1st of August, 1873. The diagram compiled from these daily observations and shewing the rise and fall of the water, is shewn by Figures 1 and 2 on Plate 111 In reference to the low water line shewn on the water guage, it may not be amiss to state that it was established from the evidence of intelligent, trustworthy witnesses who had resided for many years in the vicinity of the Bridge site. It was important to determine this with a near approach to accuracy, as, in accordance with the terms of the Bridge Charter, there had to be a clear height of 20 feet from low water level to the under side of the Bridge superstructure. It was satisfactory to find before the Bridge was finished that in this matter the legal requirements had been liberally complied with, as frequently during the progress of the work the River fell considerably below the assumed low water line. The height of low water was taken as datum and was called 100 ; all subsequent levels were referred to this datum. In consequence of the River never freezing all the way across, it was impossible to set out the position of the piers by measuring the distances between them on the ice, as was done at the Victoria Bridge at Montreal, neither could the intervals between the piers be obtained, as is frequently done in similar works, by measuring along the false works used in the erection of the permanent portions of the structure, as no fixed staging could be built in the River by reason of the great depth and velocity of the water.

For the reasons given above it was decided, at the very beginning of the work, that every piece of masonry should be set out trigonometrically. For this purpose a base line 1,789¾ feet long was measured on the Canada shore, and extended in a southerly direction from the centre line of the Bridge produced in a westerly direction.

The angle contained by the centre line of the Bridge and the base line was not so well conditioned as was desirable, being 92° 31′ on the side of the base line next to the River. But as the instrument used in determining the positions of the different points for the structure was a remarkably good one, the fact of the angles being a little too large did not make so much difference as it would have done had the instrument been one of only ordinary character and small size. But for the purpose of guarding, as far as possible, against any errors creeping into the work, a verification base was laid out on Squaw Island, and the position of every point was determined from one base line and verified from the other. The lengths of the base lines were established by measuring the exact distances between the centre of square-headed stakes, driven at short intervals and accurately ranged into line with the theodolite. The relative elevations of the tops of the stakes were then carefully taken with a level, and by calculation the true horizontal distances between them obtained. Each base line was measured carefully in the first place with a properly adjusted 100 feet chain, for the purpose of obtaining its length approximately; the length of each was then re-measured as accurately as practicable with a Chesterman steel tape, which had previously been compared with the standard measures supplied by the Phœnixville Iron Company, who were to manufacture the superstructure.

The base line on the Canada shore was checked a second time with the steel tape, prior to any work being set out from it. After the lengths of both base lines had been determined, they were connected by triangulation, and the length of the base on Squaw Island calculated from that on the Canada shore. The result was most gratifying, and gave that degree of confidence in the measurements without which the work could not have been carried on with any satisfaction.

After verifying the base lines, the next step was to calculate the angles contained by them, and the lines drawn from their southern ends to the centre points of the piers on the axis of the Bridge, and to the points formed by the intersection of this axis with the lines of the points of the abutment at Bridge seat level. These angles were all worked out to seconds, as the instrumeut used in setting them off was divided to ten seconds, and could be read by estimation to five seconds.

On the Canadian side of the River a small wooden building was erected on the highest ground near the end of the Bridge, but west of the base line, to contain the instrument to be used in "keeping up" the centre line of the Bridge across the River. This instrument was permanently placed on a stone pedestal exactly over the centre line of the Bridge. The other end of the centre line was defined by a square cedar post placed firmly in the ground about 1,300 feet beyond the east end of the Bridge. This post was painted white with a black stripe about two inches wide drawn vertically down the side facing the west. No trouble was at any time experienced in seeing this stripe through the large instrument set on masonry west of the Bridge, and there was consequently no difficulty upon any occasion in ranging the caissons, piers, &c., into line with the axis of the Bridge.

The above description of the preliminary arrangements for setting out the works refers wholly to the Bridge across the Niagara River. For the Bridge over Black Rock Harbour exactly the same course was followed, excepting that the base lines were not quite so long, and that the centre line or axis of the Bridge was not defined by an instrument set in masonry at one end of the line and by a squared post at the other. This line was established by a stout stake driven level with the ground near the Niagara Street, with a nail in the centre over which a theodolite could be set, and by another stake driven on the top of the west bank of the Niagara River exactly in the centre line produced.

An account of the details of the plan pursued in giving the position of the caissons and piers will not be inserted here, as it can perhaps be more conveniently introduced when describing the foundation, works, and masonry.

CHAPTER III.

PROGRESS OF THE WORK—DIRECTORATE AND STAFF EMPLOYED.

When the construction of the Bridge was begun in the early part of 1870, it was determined to commence with Pier No. 1, next the Canadian shore, and to build regularly towards the east, postponing the erection of the west (Canada shore) abutment till the winter, when operations in the River were impracticable. In pursuance of this plan Piers Nos. 1, 2 and 3, numbering from the west or Canada shore, were built during the first season; Pier No. 3 was finished on the 23rd December. Taking into account that the first caisson was not launched until the 13th July,—that everything connected with the works in the way of plant had to be provided, and a system of operations had to be inaugurated and organized involving many points of great uncertainty and difficulty,—fair progress was made during the first season. In the month of January, 1871, the west abutment was begun, and was finished in the month of April following. With the opening of the spring of 1871, vigorous measures were taken to carry out the programme drawn up at the commencement of the work. A caisson was launched for Pier No. 4 in September, 1870, and an effort was made to sink it in May, 1871, but for reasons, which will be detailed in a subsequent chapter, it did not prove successful. It was not considered advisable to make any further attempt to erect this pier that year, but to go on with No. 5, for which a caisson was launched in May. In July it was ready for sinking, but the same untoward accidents occurred when trying to put the one for No. 5 into position which prevented the placing of Caisson No. 4.

By this time the season was so far advanced that all idea of doing anything more in the river until the following year had to be abandoned. Although it was impracticable to carry on masonry in the River until 1872, there were no reasons why the abutment in the east side of the River on Squaw Island, and the Bridge over Black Rock Harbour, should not be proceeded with. Measures were therefore taken to go on with these works at once. The first pile for the east abutment of the Black Rock Harbour Bridge (known as Abutment No. 4) was driven on the 28th July, for Abutment No. 3 on the 2nd August, for Pier No. 9—the pivot pier—on the 16th August, for Pier No. 10 on the 28th August, and for Abutment No. 2—the east abutment of the main Bridge—on the 14th September. A glance at these dates will show the determination to proceed with the works most energetically, and affords convincing evidence that the unsuccessful attempts to found Piers Nos. 4 and 5 had not a chilling or depressing effect upon the prosecution of the enterprise, and that no doubts were entertained of finding a way to secure sufficient foundations for the deep water piers.

In the early part of August the masonry for Abutment No. 4 was begun, and was finished for the reception of the iron work early in the autumn. Abutment No. 3 was begun in September and finished in October, 1871. The masonry of Pier No. 10 was built during the months of October and November, while the first stone of Pier No. 9, or the pivot pier, was laid on the 3rd November, 1871, and the last on the 28th March, 1872.

Nothing was done to Abutment No. 2, on Squaw Island, during 1871, except driving the piles and putting on the timber platform for the foundation, so as to insure an early start in 1872. The masonry of this abutment was begun on the 30th March, and completed on the 1st June following. It was fortunate that the foundation of this abutment had been prepared in the previous autumn, so as to enable a beginning to be made early in the season, as work in the River was retarded by the unusually late period at which the last of the ice passed down the River; it was as late as the 23rd May before it had wholly disappeared. As soon as practicable the building of Pier No. 8 was commenced, and it was completed in July. Pier No. 7 was finished about the end of August, Pier No. 6 on the 9th November, and the last stone of Pier No. 5 was laid on the 17th December. This finished building operations for the year 1872.

In addition to the stone piers built during this season a wooden rest pier for the upper end of the main draw girder was erected. At the close of 1872, as will be gathered from the preceding account, the only pier remaining to be built was No. 4. The caisson for this pier was placed in position on the 7th July, 1873, and the last stone of the pier and of the Bridge was laid on the 4th October, 1873.

Although during the building season of 1871 no masonry was laid in the Niagara River, the iron superstructure over three spans, between Nos. 1, 2 and 3, was finished by the 1st October. In February of the following year, 1872, the superstructure of the Bridge over Black Rock Harbour was commenced, and finished early the following June.

In July and August Span No. 9 of the Main Bridge was erected, and the River draw girder was swung for the first time on the 3rd January, 1873. During the summer of 1873 Spans No. 6, 4 and 5 were erected in the order in which they are named, the last mentioned span being lowered on to the masonry on the 23rd October, 1873.

During the winter of 1871-2 the piles for the trestle work, spoken of in Chapter No. 1, extending across Squaw Island and connecting the two Bridges, were driven, but the trestle work was not wholly completed until the summer of 1873.

The first locomotive crossed Black Rock Bridge on the 24th July, 1873, and the Bridge across the Niagara River on the 27th October following.

DIRECTORATE OF THE INTERNATIONAL BRIDGE COMPANY,

AND

STAFF EMPLOYED IN THE CONSTRUCTION OF THE BRIDGE.

INTERNATIONAL BRIDGE COMPANY.

Directors.

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HON. E. G. SPAULDING, *Vice-President.*
HON. JAMES FERRIER.
JOHN BELL, Q.C.
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JOSEPH HOBSON	*Resident Engineer.*
J. G. MACKLIN	*Assistant Engineer.*
WILFRED BAILEY	*Assistant Engineer and Draughtsman.*
W. J. GUYLER	*Inspector of Masonry.*
GEORGE HUGHES	*Inspector of Iron Work.*

Chief Contractors.

C. S. GZOWSKI, C.E. - - - HON. D. L. MACPHERSON.

Staff of Chief Contractors.

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C. S. GZOWSKI, Junr.	*Cashier and Accountant.*
T. C. SCOBLE	*Assistant Engineer.*
GEORGE ROBINSON	*Assistant Engineer.*
OTTO MEYER	*In charge of Anchoring, Sinking Pontoons and Dredging.*
JAMES HAGGART	*Captain in charge of Tugs, Scows, &c.*
S. R. CURTIS	*Captain of Tug "International."*
WEBSTER COLLINS	*In charge of the Dredge.*
FRANK DAVIS	*Diver.*
JOSEPH BOUCHER	*Diver.*

J. MORRISON	*Contractor for Masonry*	*for Chief Contractors.*
HENRY MACFARLANE	*Contractor for Caissons and Timber Work generally*	"
J. E. BAGLEY	*Contractor for Erecting Iron Work*	"

CHAPTER IV.

FOUNDATIONS AND SUBAQUEOUS WORK.

Surveys and examinations, with the soundings that were taken, brought to light the fact that for a distance of over 600 feet from the Canada shore the bed of the River consisted of rock almost smooth, and that for about 700 feet from Squaw Island the bottom was composed of strong clay covered with gravel. Respecting the intervening 500 feet in the middle of the River, the same trustworthy information could not be obtained, but the conclusion arrived at after the most searching investigation, under very adverse conditions, was that the bottom was rock.

A good deal of difficulty was experienced in conducting this investigation. Borings could not be made without incurring expense and loss of time that would go a long way towards building the piers. To explore the bottom of the River flowing at the rate of nearly six miles an hour, by divers, at a depth of over 40 feet, was quite out of the question.

The conclusion, therefore, after making the examination and obtaining the most reliable evidence, was that Piers 1, 2, 3, 4 and 5 could be built upon rock without removal of gravel or any other material beyond perhaps some few boulders or loose pieces of rock.

Having arrived at that decision, the best course to adopt in putting in the foundations had next to be considered. Ordinary coffer-dams, in deep water flowing with a high velocity over rock bottom, could not be used. Other methods were proposed and discussed, and the plan ultimately determined upon for Piers 1, 2, 3, 4 and 5 was a water-tight floating caisson, to be sunk directly on the rock where it was not covered by a deposit.

For River Piers Nos. 6, 7 and 8, and for those in Black Rock Harbour (known as Piers Nos. 9 and 10), under all of which there was a great depth of clay, it was decided to drive [piles; to cut them off at a uniform level as closely as possible to the bottom, and sink upon them water-tight caissons similar to those sunk upon the rock; round the piles heavy "riprap" to be thrown to avert the danger of scour. Neither of these plans was new, and therefore not experimental; the latter has been used in many instances, the former had almost fallen into desuetude.

Mr. Mylne, in building Blackfriars Bridge over the River Thames in London, and Mr. Labelye, in constructing Westminster Bridge over the same River, employed water-tight caissons sunk on the bed of the River; but at Westminster Bridge the bottom was clay, and the plan did not prove quite successful, owing to the scour which took place under some of the caissons, although pits had been dredged for their reception. This mode consequently became discredited to a certain extent; but the fact of an injudicious application of it having resulted in partial failure was no reason for rejecting it where it could be employed under more favourable conditions.

There are many examples of foundations formed by piling for the reception of a water-tight caisson. Among them may be mentioned the Long Bridge at Plymouth, England, and a very fine railway bridge over the Meuse at Liege, France.

No professional engineer or practical bridge builder familiar with subaqueous foundations would consider them defective or objectionable on account of timber entering partly into their composition. But as, during the progress of the International Bridge Works, questions have frequently been asked whether it was not a source of weakness in the first place, and of serious danger ultimately to the stability of the structure, to use timbers in foundations, it may be stated that timber immersed in fresh water is not subject to decay. Wood that has for hundreds of years been buried in some of the bogs of Ireland has been taken up in a perfectly sound state.

Piles driven by the Romans for foundations of some of their bridges nearly 1800 years ago are still quite sound. A remarkable confirmation of the assertion that timber is imperishable from decay under water is also to be found in the remains of Trajan's bridge across the Danube, near Tchernetz in Turkey, where the exterior of many of the piles has become petrified, while the interior is as sound as on the day they were driven.

The plans devised, as already explained in general terms, for the foundations of piers were believed to meet all the requirements of the case; but experience, gained in attempting to place caissons Nos. 4 and 5, revealed that the bottom of the River where they were to stand, instead of being smooth rock as was supposed, consisted of large boulders intermixed and packed with gravel. The removal of this material overlying the rock was considered absolutely necessary, and led to changes in the plan of foundations for Piers Nos. 4, 5 and 6, for which it was found necessary to modify and extend the original plan of caissons.

Several plans were proposed and carefully considered. At length it was determined to construct large bottomless caissons of wood to enclose a space somewhat larger than that occupied by one of the ordinary water-tight caissons used for Piers Nos. 1, 2 and 3. The object in enclosing this space was to obtain an area of still water in which divers could work, and to admit of vertical dredges being employed for the removal of the deposit from the surface of the rock.

The bottom of the large caisson to have wedge-shaped cutting edges, so that as the gravel was removed from its interior by dredging, the caisson would settle down vertically. When the rock was made bare within the caisson, level it, if necessary, and then sink on it an ordinary water-tight caisson.

The plan of caissons having been described in general terms, a detailed account may now be given of their form, construction, methods of anchoring and sinking.

PIER No. 1.

The soundings taken for this pier showed a depth of water on the west side of the site 9 feet, and on the east side 10 feet. In the direction of the stream the water was uniform in depth. The rock, although sloping to the east, was found to be free from twist or "winding," and no difficulty therefore existed in the way of framing a caisson to fit it.

This caisson was built of sawn pine timber 12 inches square, and was rectangular at the stern and pointed at the bow; its length from the stern to the shoulder at the back of the bow was 47½ feet, its width 16 feet, and its length over all, from stem to stern 55 feet. The sides and ends were perpendicular. At the angles the timbers were halved and bolted together. All the timbers, both in the bottom and sides, were bolted together with ⅞ inch square iron rag bolts, 2 feet 9 inches long, driven in each course 6 feet apart, each bolt being long enough to pass through two timbers and 9 inches into the third. Each pair of timbers was in reality bolted together every two feet. The caisson was built up to a height of 9 feet in this way; it was then sheeted all round the outside with 3-inch pine planking securely spiked to its sides, and the bottom was covered on the inside in the same manner with planking of a like thickness. The joints of these planks were thoroughly caulked and pitched, so as to render them water-tight.

If built only 9 feet high, the caisson, when sunk to the rock, would have been wholly under water. To raise it above the level of any ordinary flood in the River, 4 feet in height was required to be added to the portion already built; but as it was intended when the pier was finished to remove the upper four feet, and to leave only the bottom section in the water, it was necessary to build it separately, for the sake of taking off the upper portion of the caisson, and afterwards to connect it by long screw bolts passing through the side and end timbers of the top part, as well as through the upper timber of the lower portion, under which (upper timber) nuts were placed to receive the ends of the rods.

The method of connecting the two sections will be more easily understood by referring to Plate No. V. As soon as the two portions of the caisson were firmly connected by these bolts, the seam between them was caulked, and the upper part was planked and caulked in the same way as the lower part had been.

The general form of all the water-tight caissons is shown on Plate No. V. For Nos. 1, 2 and 3 only one thickness of 12-inch timber was used for the bottom, and in every instance the amount of internal bracing was regulated by the depth of water in which the caisson had to stand. In No. 1 comparatively little bracing was needed, and only one tow post was required; but in deep water the caissons were braced exactly as represented on the drawing, and three white oak tow posts, from 16 to 18 inches square, were used. None of the braces below the concrete level were removed, the concrete being packed carefully under and around them, but everything that interfered with the masonry was taken out as the work progressed. No brace was, however, disturbed before it was actually in the way of the masonry, and not even then was it cut out, until the wedges had been firmly driven between the stone work and the sides of the caisson to resist the outside pressure of water

After the pier was finished, the upper portion of the caisson was detached easily from the lower one by unscrewing the bolts by which the two sections were connected, and it was removed.

This first caisson was launched on the 13th July, 1870. As soon as it was in the water the work of putting concrete into it was begun, and was pushed on vigorously until 4 feet were in it, which caused the caisson to draw nearly 9 feet of water. As this was nearly the depth of the shallowest water at the site of the pier, it became necessary to put the caisson into position before putting in more concrete. It was therefore towed from the service ground, and placed in position on the 4th August. The method followed in placing it was as follows:—

The caisson was towed down the River until within a distance of 600 feet of the position it was to occupy. An anchor was then dropped from its bow, and the caisson was lowered very slowly by letting out the cable attached to a tow-post until its stern reached the point which would be ultimately occupied by its bow. A diver was then sent down to examine the ground upon which it would stand. He reported the bottom smooth rock, with only one large boulder, which was removed. The reason for the examination of the bed of the River being deferred until the caisson had been lowered to near its permanent position, was the impossibility of a diver working in the current until protected from it by the caisson itself. When the exploration of the site for the pier had been completed, the caisson was again lowered down the stream until its stern was 19 feet below the centre line of the Bridge, at which distance from the stern, and parallel to it, a beam was spiked across the caisson into which three poles were inserted, one at each end with a white flag attached, and one in the centre with a red flag. These pickets were for the observers on shore to sight upon when giving the position. When the caisson was far enough down the stream,—which was known from the signals displayed by the person at the instrument placed on the centre line of the Bridge, attention was given to the signals shown by the transit man at the south end of the base line on the Canada shore, who, having turned off the proper angle from the base line, was watching the picket with the red flag in the centre of the caisson. As soon as he gave the signal "all right," which was done by displaying a red and white flag simultaneously, the position of the caisson was again examined as regards the centre line of the bridge. When the three poles or the cross beam of the caisson were brought into range with the instrument on the centre line of the Bridge, and the middle pole was right with the instrument at the south end of the base line, the caisson was then exactly in position and was ready for sinking, which, in the case of No. 1, was done partly by loading it with stone, and partly by letting water into it.

The operation of placing the caisson was exceedingly tedious and almost irritating, as the movement to bring it into line with one instrument was apt to disturb its position with the other, and it required numerous trials to make it succeed.

In placing the caisson many details were introduced, some of which appear too trifling to mention, but they were of material service, and answered their purpose so well that they were rigidly adhered to during construction. For example, to enable the men engaged upon the caisson to know approximately its position as regards distance from the shore, a code of signals was arranged with the transit man at the south end of the base line, who had two flag poles erected, one with a red and the other with a white flag: both flags could be run up or down the poles as occasion required.

When the red flag was at the top of the pole, it indicated that the caisson was a great deal too far west; when half way down the pole, it signified that the caisson was within 10 feet of being far enough east; and when within 3 feet above ground, it meant that a movement towards the east of less than 6 inches was required. The signals with the white flags conveyed the same instructions as to distances required to be gone towards the west. Both flags flying at the bottom of the poles announced that all was right so far as distance from shore was concerned.

For obtaining the positions approximately with respect to the centre line of the Bridge, the course pursued was very simple, being nothing more than placing two flag poles on Squaw Island exactly in range with the centre line of the Bridge, These poles enabled those on the tug boat to line the caissons so closely, that signals from the observer at the instrument were required for the final setting only.

When the three poles inserted into the cross-timber, spiked to the top of the caisson 19 feet from its stern, were on the axis of the Bridge, the longitudinal centre line of the caisson was at right angles to this axis.

This caisson being the first that was placed, a good deal of interest and some anxiety was felt when working it into position; but although the operation was tedious, comparatively little difficulty was experienced. For the purpose of steadying the caisson laterally, before it actually grounded, hawsers were extended from it to the Canada shore.

After the caisson was in place, a delay occurred in loading it with additional concrete; the consequence was that four days after it had been placed, the caisson was lifted and moved 30 feet east by the water rising suddenly nearly two feet.

The accident, although excessively annoying as evincing a want of precaution, did not cause much trouble, but it clearly and practically showed the treacherous nature of the River, and the absolute necessity of being prepared for a sudden and unexpected rise of water.

After the caisson was fairly placed the second time, two feet more concrete were put in, making 6 feet in all.

The final elevation of the surface of the concrete was 97.30. The masonry was commenced at this level.

PIER No. 2.

The caisson for this pier was of the same general description as that for Pier No. 1. Its length from stern to shoulder was 45 feet 9 inches, and from stem to stern 54½ feet; its width was 17 feet 2 inches, and height 20 feet. There was no occasion to frame its bottom irregularly, as the bed rock upon which it had to stand was quite level. The sides and bottom were sheeted with plank similarly to No. 1, and the seams between the planks were caulked. They were also heavily payed over with pitch, as it was desirable to take additional precautions against leakage. Owing to the greater depth of water, a regular system of internal cross-bracing was introduced to prevent leaks, and resist the pressure of the external water.

This caisson was built to the full height on the stocks. It consisted of two sections, the lower one being 11 feet high, the upper one 9 feet high, to be removed at the close of the work.

It was launched on the 6th August, 1870, and was loaded with concrete to a depth of 7 feet before being removed from the service ground to near the position it was finally to occupy.

Before attempting to take it down the River a large barge was lashed to each side of it. These barges added very much to the steadiness of the tow, while they at the same time did away with all risk of the caisson being upset in the current.

Before moving the barges and caisson from the wharf, the former were loaded with broken stone, sand and cement for the concrete, so that the work of putting it into the caisson could be pushed forward the moment it was in place.

In lashing the barges and caisson together care was taken to connect them in such a way that the latter could sink independently of the former. The barges were about 40 feet longer than the caisson; they were allowed to project beyond it at each end, and were connected by chains stretched across each end of the caisson.

In this way the caisson was embraced between the barges without being actually connected, and could consequently be sunk without them. Before describing the mode in which the caisson was taken down the River, and the method adapted for determining the position of the point at which its anchor was to be let go, it may not be out of place to remark that precisely the same course was followed for taking down and anchoring all the caissons subsequently placed as was pursued for this one. No other plan, possessing greater advantages, suggested itself during the progress of the work.

These observations will save a good deal of repetition when describing the foundations of the other piers.

On the 1st September, 1870, the caisson was floated down the River, guided by two tugs, each attached by hawsers to the two posts of the caisson. Working the engines of the tugs sufficiently to control their movement in the current, gave the required direction to the caisson, and allowed it to descend the River with a velocity somewhat less than the current. The anchor was dropped when 600 feet above the Bridge, and the caisson itself was lowered very gradually down the River by letting out the cable, as was done in No. 1.

As it neared the point at which the anchor was to be dropped, the engines of the tugs by degrees worked up to such a speed that the caisson was held nearly, if not quite, stationary.

This was necessary, as the point at which the anchor had to be let go had to be determined instrumentally from the shore.

The way of doing this was to put up two flag poles on shore in a line parallel to and 600 feet distant from the axis of the Bridge. The bow of the caisson was brought into this line, and was then moved east or west in accordance with signals given by the observer stationed at the south end of the base, who had turned off such an angle that the line of sight through his instrument intersected the line in which the two poles were placed at the point in which it would also be intersected by the longitudinal centre line of the pier produced up stream.

The anchor was dropped from the bow of the caisson directly the signal was given that it was right, and it was then very gradually and slowly lowered down stream by letting out the cable.

When the stern of the caisson was about 40 feet above the centre line of the Bridge, and after it had been further loaded with concrete to within a foot of the bottom of the River, a diver was sent down to examine the rock. He was able to do this without any difficulty in the slack water behind the caisson. After having examined the bed rock the full width of the caisson, and for a distance of 6 or 8 feet down stream, and reported, the caisson was allowed to go down stream 5 feet more, when he again examined the bottom in advance of it.

These operations, of letting down the caisson and inspecting the bed of the River, were repeated until the caisson was immediately over the permanent site for Pier No. 2.

The bottom was found to be of good character, requiring only the removal of a few boulders.

Three anchors were used for holding and for bringing the caisson into place, one leading up stream directly from the bow, to which reference has already been made, and one at each side of the bow, nearly at right angles with the first, bearing a little up stream. In placing the caisson upon the rock, the same course was followed as in No. 1. The operation, however, proved to be much more tedious and troublesome, owing to the additional depth of water and increased current. The greater part of three days was consumed by it. The caisson was finally placed on the 7th September, 1870. The concrete was brought to the full height, and levelled three days later, when the first stone was laid. The elevation of the bed rock under the pier was 84·00, and of the finished surface of concrete upon which the masonry was founded was 93·64.

No "riprap" was put around either this caisson or No. 1, as there was no possibility of any scour.

PIER No. 3.

The caisson for this pier was not built to the full height on the stocks, but was launched on the 6th September, 1870, when only 20 feet high. It was considered unadvisable to put in all the side timbers before it was in the water and partly ballasted with concrete, as it would have been top-heavy, with a tendency to upset.

When it had been loaded with a few feet of concrete, additional timbers were built on until a height of 26 feet was attained. Sufficient concrete was then put in to sink it to the depth of 18 feet, being within one foot of the depth of water on a reef extending across the River at the upper end of Squaw Island. On the 8th October, 1870, the caisson was floated to within a short distance of the Bridge site. Four powerful tugs were required for this service. The side barges that were considered useful in placing No. 2 were deemed absolutely essential to the safety of No. 3.

The depth of water and strength of current at the site of this pier being very much greater, it was thought advisable not to lower the caisson within 40 or 50 feet of the position its bow would ultimately occupy before it was almost ready for sinking, as it was feared that the great strain that would be thrown upon the anchors might cause them to drag a little, and whether the anchors dragged or not, the caisson would certainly, while being loaded, descend the stream a few feet by the straightening out and tightening of the cables.

After it was anchored, the work of putting on the timber required to bring it to the height of 30 feet, and of loading it with concrete, proceeded satisfactorily until the evening of the 17th October, when a violent south-west wind began to blow.

During the night its force increased so much that the anchors dragged, and the caisson was carried about half-a-mile down the River, where it grounded.

During the gale the water rose upwards of three feet above its usual level, and continued at this height until the storm abated. The caisson was in consequence carried much further on the bank than it would have been had the River been in its normal state when the anchors gave way, and added greatly to the difficulty of moving it, as it became imbedded in the gravel when the water subsided to its usual level. The season was getting late; there was therefore no time to be lost in adopting vigorous measures to bring the caisson back to its place. A considerable quantity of the concrete was immediately thrown out, large holes were cut through each side of the caisson opposite each other, just above the level of the decks of barges, which were placed one on each side. Through these holes heavy square timbers were inserted long enough to reach across the caisson and barges. The caisson was then raised by means of lifting screws. The operation of lifting so large a mass was a slow one.

On the morning of the 24th October the caisson was afloat again, and by means of seven of the most powerful tugs that could be obtained in Buffalo was brought back to the place from whence it had drifted, and where it was once more anchored with three anchors. No further accident happened to it, and it was placed on position on the 2nd November, 1870.

Fortunately, although the rock at the site of this pier was not level it was free from any twist, and the caisson consequently was not distorted by the weight of the concrete and masonry, or affected in its position. The inclination of the bed rock towards the east, in the width of the caisson, was 6 inches; towards the south, or up stream, it was 3 feet in the length of the caisson.

A serious difficulty was narrowly escaped on the location of this caisson, as but a few feet south of its bow a ledge of rock, presenting a vertical face of 4 feet in height towards the north, extended some distance east and west.

The average depth of water at this pier was 28 feet, the elevation of the surface of concrete was 87·30. At this level the masonry was begun, and when the pier was finished the upper portion of the caisson was removed to concrete level.

This caisson was built in two sections, similarly to those for Piers Nos. 1 and 2, and no material change was made in its general form and construction. The most important alteration consisted in the sheeting being dispensed with.

It was found in Caissons 1 and 2 that the planking formed a skin much too easily injured by the rough usage to which it was occasionally exposed. A blow from a barge or a tug, particularly when it was struck near the corners, was apt to start the planks and cause a leak. It was therefore considered much better, when building Caisson No. 3, to leave off the planking, and to caulk between the solid timbers from the outside.

Before it was launched its bottom was caulked from below. Each joint or seam was caulked with two "threads" of oakum; it was then "hawsered," and afterwards received another "thread." In this way the oakum was forced about four inches between the timbers. All the seams were thoroughly pitched with wood tar. It was found that this mode of caulking between the side timbers was much better than the plan first adopted of sheeting and caulking between the planks, and was consequently adopted for all the caissons built subsequently to No. 2.

PIER No. 4.

From the very beginning of the work it was anticipated that the most difficult part of the whole undertaking would be found at Piers No. 4, 5 and 6, as they would stand in the deepest water and be exposed to the most violent current.

As the work advanced during 1870, the formidable nature of the task was clearly realized. The ordinary current in the middle of the River, when taken in connection with a depth of over 40 feet of water, was quite sufficient to make the operation of sinking a caisson there one of a most serious character. And it was not reassuring to know that the water was liable to be raised by a south-west gale, in the course of a few hours, 4 feet above its usual level, and the current to be increased to twice its ordinary velocity.

When taking into consideration this last-mentioned condition, it must be recollected that the destructive power of running water is not represented simply by the numbers which indicate the proportion between the normal and the accelerated velocities. For, while the rate of movement is only doubled, the force of the water is increased according to the sixth power of its velocity. As these south-west gales, that cause the rise in the River, come up suddenly and without warning, it was essential, in providing appliances, to be prepared for the worst that could occur.

Two additional anchors of the largest dimensions, with a full complement of cable, were therefore provided. Each of these anchors weighed 4 tons. They were such as are used by the largest ships of war in the American Navy. Although the magnitude of the task of placing the deep-water caissons was fully realized, no apprehensions as to its success were entertained.

While Piers Nos. 1, 2 and 3 were being built, nothing had occurred to produce an impression that the mode of putting in the foundations, which in their case had been so successful, would be found unsuitable when applied to Piers Nos. 4 and 5. It was not therefore thought necessary to make any changes in the plan of caissons further than to give them additional strength to meet the increased strains to which they would be exposed in consequence of increased depth of water and force of current.

On the 20th September, 1870, a caisson was launched, which it was intended to use early in the following year for Pier No. 4.

On the 5th May, 1871, it was floated to near the site of the Bridge, and moored by five anchors; the front one, or one directly up the River, being a "Trotman," weighing 3½ tons. The other four were also of the largest size, and were ranged two on each side, leading diagonally up stream. Before making the final examination of the bed of the River, and prior to floating the caisson directly over the site to be occupied by it, 11 feet more timber were added to it, making a total height of 41 feet. It was then loaded with concrete till a draught of about 38 feet was obtained. An attempt was then made on the 27th May to place it in position. Everything went on without any trouble until the signal "all right" was given, and the caisson had actually touched bottom at one point, when one of the side cables, although formed of 1⅝ inch iron, parted, and threw so sudden a strain upon the remaining cables, that the anchors began to drag and the caisson to swing violently from side to side in the current. After oscillating in this way for perhaps nearly a minute, it grounded nearly 60 feet below the line of the Bridge.

About a week after, and before it was practicable to procure proper appliances for raising it, a violent gale removed all that portion of the caisson above the concrete, about 12 feet deep, and carried it down the River. No further attempt was made to obtain a foundation for this pier during 1871.

Meanwhile, when endeavouring to place a caisson for Pier No. 5, the unwelcome discovery was made that what had always been supposed to be hard rock at the sites for Piers Nos. 4 and 5, was in reality boulders, with the interstices between them filled with gravel.

As soon as this was known it became apparent that another plan for foundations would have to be devised, as all the loose material overlying the rock would have to be removed.

Mr. Hannaford, the Chief Engineer of the Company, having given the matter his most careful consideration during the autumn of 1871, determined to use bottomless caissons, which were to enclose water-tight caissons similar to those previously used.

Although the general idea of a bottomless caisson was approved and adopted, it was considered of great importance, before deciding upon its exact form and size, to make a number of experiments with models of various shapes and dimensions.

The plan of the caissons ultimately adopted and used for Piers Nos. 4, 5 and 6 is shewn in Plate No. IV. Their extreme length, exclusive of the fin at the stern, is 97 feet; their width, from out to out, 31 feet. The bow of the caisson pointed, being formed of two short sides containing an angle of 90°. The stern is also pointed, but much more sharply, forming an angle of only 60°.

The experiments made with the models shewed conclusively that their steadiness, when lying in a swift current, was more affected by the eddy at the stern than by the pressure of the stream at the bow.

Deducting the pointed portions at bow and stern of the caisson, the rectangular part was only 54½ feet long. The walls or sides were solid for about 6 or 8 feet from the bottom; above this height they consisted of two "skins," with a clear space between them of 2 feet. The bottom of the sides or walls is V shaped, shod with a cast-iron shoe to protect the timber from abrasion, and to form an edge to penetrate gravel or clay. This solid part was composed of three courses of vertical timbers 12″ x 12″, set close together and spiked with ⅞-inch rag bolts between 2 and 3 feet long. The outside of the outer row of timber immediately above the cast-iron shoe is dressed down 2 inches, so that a course of 2-inch planking, spiked horizontally to the outside of the first course of vertical timbers, is flush with the face of the shoe. In the inside of the caisson, horizontal timbers 12″ x 12″ are bolted to the inner or third row of vertical pieces.

The object of the longitudinal planking on the outside and of the 12″ x 12″ pieces on the inside of the vertical timbers is to tie them thoroughly together. The bottom of these vertical timbers, and so much as was requisite of the inner horizontal timbers spiked to them, were bevelled to present a chisel edge with the slope on the inside of the caisson. The outside of the caisson presented a vertical face from the edge of the shoe all the way to the top. As it was expected that the depth of gravel or clay into which it would be necessary for the caisson to penetrate would be small, it was not considered worth while to make the outside of the walls with a batter to prevent it from binding in the material through which it had to pass.

From the preceding description it will appear that the walls above the bevelled portion at the bottom were 4 feet thick, made up, counting from the outside, of 3 vertical timbers and 1 horizontal. Above this solid part they consisted, as already stated, of two skins, with an interval of 2 feet between them. To connect these skins, vertical timbers, forming the inner or central part of the solid portion of the walls at the bottom, were carried up in pairs at intervals of about 6 feet all the way round the caisson. These vertical timbers served a double purpose—to tie the skins together and to keep them at a uniform distance apart; they also formed a very strong connection between these skins and the solid section of the walls.

For the purpose of giving additional strength at the angles of the caisson, the timbers forming the inner skin, at vertical intervals of a few feet, were increased in length, so that they might be extended across the space between the skins, and dovetailed into the outer skin. The timbers of the inner skins, thus produced, were halved into each other where they crossed.

To give stiffness laterally to the whole caisson 48 cross ties were inserted. These cross ties extended from side to side of the structure, and were dovetailed into the wall timbers. Four oak snubbing posts, or "bits," 18″ square, were built in near the bow, these were placed between beams, extending across the caisson, and at the same time, to give additional strength, horizontal braces were carried from these beams, extending across the caisson; for the same purpose, horizontal braces were carried from these beams forward to the walls of the bow, these walls being made solid where the bearing of the braces came.

In short, wherever additional and exceptional strains were expected to occur, extra resisting power was provided. Beyond the stem a fin or immovable rudder (if such a term does not involve a contradiction) was carried out 25 feet into the stream to the depth of 24 feet only.

The caisson, before being launched, was built to a height of about 14 feet. Additional timbers were then put on, and when a draught of about 18 feet was attained, it was floated to the vicinity of the Bridge. Before floating the caisson down the River, which was done on the 12th June, 1873, a large can buoy was anchored in line of the site of the pier, and about 100 feet down stream, as a guiding point for floating the caisson in the right direction, it being desirable, when anchoring it, that it should be so located as to avoid the necessity of moving such an unwieldly mass as it presented with the barges at its side either to the east or west.

When it was at the spot for letting go the anchors, six powerful tugs, working two and two abreast, were required to hold the caisson in position. Before leaving the wharf the cables were all attached to the caisson, and the anchors were loaded on the side barges, and were so arranged that they could be dropped or removed without their cables fouling with each other. The plan of anchorage is shewn on Plate No. VI. Anchors A, B and G were loaded on Barge No. 2, the two last named being deposited at the point *y*. The Anchors D, E and F were loaded on barge No. 1, the first named being at the point *x*. As soon as the bow of the caisson had been brought into proper position, 600 feet above the site for the pier, the Anchors C, G and D were thrown overboard, and the full strain was permitted to come on to them very gradually by slowly reducing the working of the tugs. The caisson was then allowed to descend the stream until it was about 140 feet above its final position. The object in keeping it so far above its true place was to allow for the straightening out of the cables when the full strain was upon them, and for the inevitable descent when the cables were lifted, which had to be done as each rise of five feet of timber was added to the height of the caisson. As soon as the caisson became stationary, at a distance of 140 feet up stream, the Anchors A, B, E and F were carried out and dropped into positions shown on the plan. When these side anchors were in place their cables were drawn as "taut" as practicable, so as to keep as nearly as possible the bow of the caisson immovable. The anchors H and I were then carried out from the stern and the cables were laid in festoon form. These anchors and cables were not intended to hold the stern rigidly in place, but to steady it and counteract any tendency to sheer. In short, they were designed to act like springs or elastic bands in checking and controlling lateral motion in the caisson.

The guiding principle in anchoring the caisson was to attach the cables as closely as possible to the bow for the purpose of holding it stationary, as, if the bow could be kept immovable, it was not anticipated that there would be any trouble with the stern, and in practice this was found to be the case. When the anchors were all out the work of building up the caisson was resumed. An additional height of 5 feet was put on, and then it became necessary to raise the cables to the top of this lift as they were becoming submerged by the sinking of the caisson. This work required great care. Each cable, with the cast-iron chaulk through which it passed, was raised separately, and properly secured before another one was touched. Two days were required for raising 8 cables the height of 5 feet to top of caisson.

Notwithstanding all the care which was exercised in raising the cables, it was found that the caisson went down the stream from 8 to 10 feet each time the operation was repeated, for which movement, however, provision had been made. Each time the cables were raised the position of the bow of the caisson was taken trigonometrically, and if it was found to have deviated from the longitudinal centre line of the Pier produced up stream, the error was at once corrected by cables attached to anchors A, B, E and F. These repeated trials of position were of the most satisfactory and reassuring character. It was found that the system of anchorage was so nearly perfect that the oscillations of the bow were confined to 2 or 3 inches. As the caisson was being built up by adding on the side timbers, it became necessary to sink it more rapidly than by the weight of only the superimposed material used in construction. This was done by partially filling the space between the skins with stone and gravel. The plan of loading the caissons till they nearly touched the bottom, and of adding more weight when they were exactly in position, as done with those for Piers Nos. 1, 2 and 3, was found to be defective. The extra weight could not be added instantaneously, and in the meantime there was great danger of the caisson changing its position. It was therefore determined to follow a different course in sinking the large bottomless caissons by loading them before attempting to put them into position, with sufficient weight to make them bear firmly upon the bottom, but at the same time to give them sufficient buoyancy by some temporary and easily removed attachments, keeping them afloat several inches above the bed of the River until they were brought exactly in position, then to sink them by the removal of the temporary flotation power.

The plan devised for that purpose was to lash together from 130 to 150 empty coal oil barrels in such a way that by the cutting of a single rope the barrels were detached from the caisson, which immediately sank to the bottom of the River. Each barrel had a buoyançy of nearly 400 lbs., so that in the aggregate they represented a sustaining force of from 26 to 30 tons of 2,000 lbs. each.

Knowing the buoyancy of the barrels and the size and weight of the caisson, it became a matter of very simple calculation to determine how far from the bed of the River the caisson could safely be kept floating while being worked into position. To give further security against any displacement of the caisson, six iron bars,—16 ft. long by 4 inches in diameter, and sharp pointed, three on each side,—were dropped through openings in the sides of the caisson at the same moment that the lashing of the barrels was cut. Plate IV. represents some of the openings and iron bars.

These bars were arranged to have a clear fall of fully 30 feet. On the 7th July, 1873, this caisson was successfully placed on the bottom of the River. The course pursued in giving its position was substantially the same as that followed in placing Piers Nos. 1, 2 and 3.

As soon as the barrels could be removed from the interior, divers were sent down to examine the bottom of the River. Their report was looked for with much anxiety, as there were different opinions as to what it would be; but the prevailing impression was that the bed of the River was rock, with a very thin covering of gravel.

The divers reported that about half way along the caisson a gravel band extended transversely, upon which the caisson rested, but that it was not bearing at either end, and that at each end the bottom of the River was rock. This intelligence was satisfactory, as no difficulty was anticipated in removing the small quantity of gravel which was reported to overlie the rock near the middle of the caisson. Sand-bags were lowered, and placed by the divers to prevent the strong current from rushing in through the opening below the shoe of the caisson near the bow. One of Morris and Cumming's dredges was then set to work to take out the loose material from the interior of the caisson. The material dredged up apparently confirmed the report of the divers, as it consisted principally of loose shale, such as is frequently found overlying rock. As it was determined to remove the whole of this loose material, the dredge was kept steadily at work for several days; but to the great surprise and disappointment of all concerned, it suddenly broke through the hard crust into soft material. A few more hours' work unmistakably revealed the fact that the bed of the River at this point consisted of a hard shell of indurated or compacted gravel, intermixed with flat stones, overlying 9 feet or more of coarse sand and crushed shale, under which the rock was found, at a depth of 48 feet below the surface of the River. The depth of water where the caisson stood was 38 feet before any dredging was done. A most arduous undertaking was before us,—to remove a depth of nearly 10 feet of this loose material from the whole area of the caisson. The most difficult and slowest portion of the dredging was to break through the hard surface. The course pursued in working the dredge was to take out longitudinal trenches on each side, close to the caisson. The divers then removed the material from under the shoes, and pulled it into these trenches, from where it was taken up by the dredge. The whole process proved to be both costly and tedious, as the hard crust had to be taken out from under the shoes in small pieces by divers working in absolute darkness, and whose only guide was the sense of feeling. Weeks of patient labour were spent before a satisfactory settlement of the caisson took place. At length the difficulties were surmounted: the whole of the rock within the caisson was cleared of gravel, and the caisson itself settled almost to the rock. The cross ties were at once cut out, and the inner caisson was floated in on the 8th of August, 1873.

This inside caisson was of the same general form as those used for Piers Nos. 1, 2 and 3. Its length was the same, but its width was somewhat greater, being 19 feet. It differed chiefly from the others in the mode of bracing and in the thickness of the bottom. The depth of water at this pier was so great, that it was considered essential to use a stronger system of bracing than had yet been employed. This consisted in bolting vertical timbers in pairs to the inside of the walls of the caisson. These timbers were 8 inches by 18 inches, and were bolted with the wide side against the caisson. The distance from centre to centre of each pair of timbers was about 6 feet 4 inches.

The distance between the individual timbers of each pair was about 7 or 8 inches. The twin timbers on one side of the caisson were exactly opposite to corresponding timbers on the other. Cross ties, such as were used on the other caissons, were framed and dovetailed into the side timbers and between the above described twin vertical timbers, and shouldered on both sides from 2 to 2½ inches. The bow and stern were supported in a similar manner by longitudinal timbers extended from end to end of the caisson. This plan of bracing answered admirably. The bottom of the caisson, instead of being composed of only one or two thicknesses of 12″ × 12″ timber, was formed of 8 courses of 12″ × 12″ pieces, laid alternately longitudinally and transversely. The timbers in each course, except the botton one, which was laid close and was caulked and pitched, were placed about an inch apart, and the interstices were filled with a grout of equal parts of cement and sand. The timbers in each course were securely spiked by ⅞-inch square drift bolts to the course below. A bottom formed in this way was sufficiently strong to bridge over any equality or depression in the rock, and prevent the danger of the masonry being fractured by any unequal settlement. Over this solid timber bottom 6 feet of concrete were placed and the masonry built upon it.

PIER No. 5.

On the 18th May, 1871, nine days before an attempt was made to place Caisson No. 4, another of the same description was launched for Pier No. 5. It was floated to the vicinity of the Bridge site on the 21st day of June following. Although in the meantime the attempt to place No. 4 proved uusuccessful, it was considered that by using larger anchors and more of them success might reasonably be looked for.

No misgivings had yet been entertained respecting the nature of the bottom of the River, or the applicability of the plans that had answered so well in the early stages of the work.

In addition to the immense power required to hold this caisson in place, in consequence of its being in the deepest part of the River and exposed to the maximum force of current, provision had to be made for strains under circumstances which were of a wholly exceptional and unexpected character, and from which Caissons 1, 2, 3 and 4 had been free. These were, the liability of being struck by rafts, Caisson No. 5 lying in mid-channel for raft navigation.

It was therefore determined to use such a number of anchors and strong cables that there should be no danger of their being broken by any force that would likely be applied by rafts coming against them. An opportunity soon occurred for testing the strength of the cables and the holding power of anchors. Incidents connected with it are worth relating.

Three days after the caisson had been floated to the neighbourhood of the Bridge site, a raft of unusual dimensions came down the River. It was over 3,000 feet in length and of about 80 feet in width; the timbers of which it was composed were large, and most of them over 60 feet long.

Immediately opposite Fort Porter (Buffalo) the water rushes by at the rate of nearly nine miles an hour, while directly below the velocity is reduced to a very little over seven. The effect of this is, that unless the tug towing the raft has sufficient power to maintain the head of the raft when it gets into the slacker water at the speed acquired in the rapids, the tail of the long raft, which still remains in swift water, curves rapidly down stream until the rear part of the raft assumes the form of an immense horse-shoe. The raft in this form struck, and, it may be said, embraced the caisson and the barges, exposing the cables not only to the strain of the full weight of the raft, but to the hauling by the tug steamer, which worked to its full power endeavouring to straighten the raft.

In a very short time, perhaps not exceeding one or two minutes, the sound of crashing timber was heard and huge logs were seen to assume all sorts of irregular positions. Meanwhile the back end of the raft had swung fully and fairly into the stream, and the cables holding the caisson and scows were exposed to the tremendous strain of this huge raft and tug with a vessel attached to it. For a few moments the whole confused mass remained stationary, then it began to move slowly down stream, dragging the eight large anchors by which the caisson was held. It grounded near the lower end of Squaw Island, about 2,000 feet below the Bridge site, in about 27 feet of water.

This accident was of a grave character, involving, as it did, a serious loss of time and the expenditure of many thousand dollars. It was all the more annoying from the reflection that it might easily have been avoided had those in charge of the raft displayed even ordinary prudence.

After the accident, there was no other course to adopt but to tow the caisson back to the dock at Fort Erie and prepare it again for being anchored a second time; this was done on the 29th June. Six powerful steam tugs were required for that service.

By the 7th July following, all the eight anchors by which the caisson had been held were taken up and re-attached to it, and everything was in readiness for again anchoring it near the Bridge site. On the following day it was floated the second time down the River, and secured once more in the position it formerly occupied. By the 12th August the caisson had been built to the full height of 46 feet, and sufficient concrete had been filled in to sink it almost to the bottom. An attempt was then made to place it, but, as was the case in No. 4, the moment the caisson touched bottom it became wild and unmanageable, and dragged the anchors. It at length grounded not very far from its true position. A few hours after, it was found to have heeled over almost a foot towards the Canada shore. Next morning its west side had settled three feet.

A diver was then sent down to examine the bottom, and after several visits, reported rock under the north-west corner of the caisson, with a covering of seven feet of gravel over it.

As soon as the fact was clearly established that the bottom of the River was covered by gravel, it was decided to pump out the caisson, and to throw out of it sufficient concrete to admit of its being towed back to the dock.

It also became at once apparent that it would be necessary to modify the plans for the foundation of this pier so as to meet the unexpected difficulty of a gravel bottom, as it was essential that the pier should be founded upon rock. Owing to the season being far advanced, and to the time that would be required to mature plans to meet the exigencies of the case, it was decided to suspend all operations relating to foundations until the following year. During the autumn and winter the bottomless caissons, and general plans for founding Nos. 4, 5 and 6 were designed. A full description of these has already been given in the account of the foundation for Pier No. 4.

It may not be out of place to remark that although all uncertainty as to the nature of the bed of the River under Pier No. 5 was dispelled, the same reliable information had not been obtained by that time respecting the site for Pier No. 4; but to prevent disappointment from want of that knowledge, it was considered advisable to use a bottomless caisson for No. 4 Pier also. If the bottom proved to be rock no harm was done, while if gravel was found, it could be removed without difficulty.

The caissons for Pier No. 5 being similar in every respect to those for Pier No. 4, no description is needed. The same applies to the anchoring and sinking; they were identically the same for both piers.

On the 29th of June the bottomless caisson for this pier was launched; on the 22nd of August it was towed to the vicinity of the place where it was to be sunk and was there anchored; and after being built up to the proper height, and prepared in all respects for sinking as was done at Pier No. 4, was placed in position on the 26th September, 1872.

A great deal of trouble was experienced, whilst dredging, from some old timber which was found imbedded in the gravel and extending under the sides of it; also from several large boulders, some of which were also under the sides and prevented the caisson from settling properly. With great difficulty these were removed by the divers. A large pine stump was also discovered and brought up. At length the rock was laid bare. It was found to be irregular, and of the form shewn on Plate No. IX. The position of the caisson was somewhat altered by the removal of the material from its interior. This, however, made no practical difference, as the outer caisson carried no part of the weight of the pier; it was merely placed to enclose a space of still water, to admit of the rock being laid bare and prepared for the reception of a water-tight caisson. These purposes it served efficiently, notwithstanding a little irregularity in its ultimate form.

The next step, after stripping the rock, was to bring it to a level by filling up the low parts with stone. This was done in a very efficient manner by the diverss The cross ties were then cut out and the inner caisson floated in, built up and sunk in the same way as was done at Pier No. 4. The spaces between the two caisson, were then filled with stone thrown in at random, and the outside of the bottomless caisson was surrounded by "riprap," as shown on Plate No. IX.

PIER No. 6.

The outside or bottomless caisson used in founding this pier was essentially the same as those employed for Piers Nos. 4 and 5. There were a few changes in the details, but they are not worth mentioning.

It was launched on the 27th May, 1872. On the 22nd June following it was floated to the vicinity of the place it was intended finally to occupy, and on the 13th July it was successfully placed in position.

It was originally intended to carry this foundation to the rock, but after dredging about 5 feet in depth in the interior of the caisson, it was found to be impracticable to go any lower, as the material at that depth proved to be clay, upon which the dredge made no impression. It was therefore determined to drive piles within the caisson, and cut them off close to the bottom. Even this, although the simplest method that could be adopted, was a work of very considerable difficulty. A trial pile was first driven to ascertain the consistency of the bottom and depth to the rock. As the clay was found to be 15 feet thick, and the depth of water over 30 feet, piles nearly 50 feet long were required. The piles in this foundation were not shod with iron, as it was deemed better to drive them to the rock and bruise the points a little by two or three subsequent blows of the hammer, the weight of which was 2,200 lbs., with a fall of 35 feet. The whole space enclosed by the caisson was piled, the piles being driven 3 feet from centre to centre.

Some doubt was entertained about the practicability of cutting off piles by machinery 30 feet under water. The attempt was at the time looked upon as an experiment believed to be wholly unexampled. The great difficulty consisted in giving stiffness to the shaft carrying the circular saw. The depth of water, as mentioned, was 30 feet, and the nearest immovable bearing of the shaft was 6 feet above water. The saw was therefore working at the end of a lever 36 feet long. When sufficient pressure was brought upon the saw to cause it to work into the pile, the shaft had a tendency to bend.

Another difficulty was that the piles had to be driven and cut off before the cross ties, binding together the ends of the caisson, could be removed; therefore, after cutting off all piles at one side of a cross tie, the saw had to be lifted to the surface of the water and moved over to the other side. This involved the raising vertically of the long shaft to which the saw was attached, to a height of 30 feet—a work of great trouble, and requiring great care, at the same time of some risk to the men engaged in it.

The drawings of the saw used for cutting off the piles are shewn on Plate No. XX. It answered its purpose very well indeed, and had very little tendency to get out of order.

In water not exceeding 10 or 12 feet deep, 150 piles could be cut off by it in ten hours, after it was got fairly into working order.

At Pier No. 6, in consequence of the extreme care which had to be exercised to prevent the shaft from being bent by feeding the saw too rapidly, and of the trouble of raising it over the cross ties of the outer caisson and resetting it, not more than 20 piles were cut in the same time.

When all the piles had been cut off, stone was firmly rammed into the clay between them by the divers. In this way a uniform paving, exactly level with the tops of the piles, was prepared for the reception of the inner water-tight caisson.

The cross ties of the outer caisson were then sawn off close to the sides. This work was likewise performed by divers. The inner caisson was floated in on the

30th August, 1872; by the 26th September 5 feet of concrete had been placed in it, and the first stone of the masonry was laid.

The inside caisson of this pier was exactly the same as to size and shape as those used for Piers Nos. 4 and 5, except that the bottom was only 2 feet thick.

PIERS Nos. 7, 8, 9, 10 & REST PIERS.

The foundations of all these piers were identically the same in principle. Piles were driven in each three feet from centre to centre, and were then cut off at a uniform height close to the bed of the River. When this was not quite level at the site of the pier, as was the case at No. 7 and the rest pier, stone was rammed in between the piles and brought up to the level of their tops. Water tight caissons were then sunk on the piles with concrete.

The caisson for Piers Nos. 7 and 9, being pivot piers, was octagonal in form, 40 feet in diameter when measured at right angles to the sides. A caisson of the ordinary shape, rectangular at each end, was used for Piers Nos. 8 and 10, where there was no current.

For the rest pier—intended to support the upper end of main draw girder when open—a caisson 55 feet long and 19 feet wide was constructed. The stern of this was rectangular; its bow was pointed, being formed of two short sides including a right angle, and was made for a height of about 12 feet, with an inclination or slope of 1 to 1; above this its slope was ½ to 1. The face and shoulder of this ice breaker were sheeted with boiler plate to high water mark. The sides of this wooden rest pier were tied together by iron rods, and the interior was filled with stone.

The rest pier for the support of the upper end of the draw span in the Harbour was a rectangular caisson, 12 feet by 26 feet; its longest side being parallel to the centre line of the Bridge.

This caisson required no ice-breaker, as there was scarcely any current in Black Rock Harbour. To protect it, however, from being struck by vessels, a cluster of large piles was driven near its south-west and south-east corners. The interior of the caisson was filled with stone.

Round each of these piers a large quantity of stone was thrown, to protect them from the action of the current in the River and from dredging operations in the Harbour.

These stones varied in size from about a cubic yard downwards. They have been found to form an efficient safeguard in the River, not only against the scouring action of the water but also against the ice.

FOUNDATIONS OF ABUTMENTS.

There was very little difficulty experienced in founding the abutments. Abutment No. 1 stands on the rock.

For Abutments Nos. 2 and 3, piles were driven, and were cut off 3 feet under low water. These piles were driven in regular rows, 8 feet from centre to centre. On the tops of these, caps 12 inches square were spiked, and transversely to these a close flooring of 12 inch square timbers was laid for the reception of masonry.

In Abutment No. 3 concrete was filled in and carefully levelled between the tops of the piles and the caps spiked on to them; and between the joints of the floor upon which the masonry was founded, thin cement grout was poured.

The breast wall of Abutment No. 4 was piled, concreted, and prepared for building upon in the manner described for No. 3. The wing walls were built directly from the clay, which was hard and unyielding.

CHAPTER V.

MASONRY.

In designing the substructure of the International Bridge, the problem that presented itself for solution was to devise a plan of foundation which could be carried out without the aid of fixed coffer-dams, and a form of pier that would effectually resist the thrust of the large ice fields which descend the Niagara River during the winter and spring of each year. The mode of setting in the foundations has already been explained.

The pier that was supposed to meet the requirements of the case most fully was one with an ice-breaker triangular in plan, and with the cutting edge retreating six inches for each foot in height, the angle of the point formed by the two sides of the base of the ice-breaker being 90°. This ice-breaker, in Piers Nos. 1, 2, 3 and 8, commences at the surface of the concrete, and is carried up to an elevation of 111·16, where it is surmounted by a pyramidal hood or cope-stone; in Piers Nos. 4, 5 and 6 the ice-breaker, as above described, begins at an elevation of 90, being 10 feet under water; from this down to the top of the concrete it is still triangular in plan, but its up stream or cutting edge only recedes from the perpendicular by an amount due to the intersection of two planes battering 1 in 24. The reason for not carrying the ice-breaker all the way down to the concrete on the same slope as the upper part is, that the length of the base of the pier would have been increased without commensurate advantage. Ice fields never strike the piers more than two or three feet below the surface of the water. What comes in contact with the ice-breaker below this are masses of ice locally termed "Clampers," and pieces broken off the ice fields.

The former are generally so deeply immersed in the water, that their tendency is not to rise upon the inclined surface but to turn off either to the right or to the left. So far as they are concerned, a vertical cutting edge is therefore as good as a sloping one; with regard to the latter, they cannot climb the ice-breaker, as they are portions of the field that are forced under when it is broken up by coming in contact with the pier, and, as a matter of fact, they do not strike the nose of the ice-breaker when driven down below water in this way, but impinge on the shoulders, and are immediately swept past the side of the pier by the current; consequently, in their case also, nothing would be gained by lengthening the slopes of the cutwater.

When a field of ice is broken up by striking a pier, the general tendency of those portions of it which come directly in contact with the ice-breaker is to rise upon its sloping faces, and then fall off on each side; and it will be obvious that the less the inclination of these faces, the greater will be the probability of the ice running a long way up them before falling off. The thorough knowledge of this action of the ice which Mr. Hannaford had acquired from many years' observation on the Victoria Bridge at Montreal, convinced him that the slope given to the ice-breakers at that Bridge—one to one—would not answer at the International Bridge by reason of the superstructure of the latter being only 20 feet above low water; if a slope of one to one had been adopted, the danger of ice running up the cutwaters and striking the trusses would have been very great.

These considerations led to the ice-breakers being designed with a slope of 6 inches horizontal to 1 foot vertical. The experience of three winters has clearly demonstrated the correctness of the opinion entertained in reference to this matter. The slope of the ice-breakers has been found to be amply sufficient to divide the ice easily, and at the same time not to be so great as to create any danger of its coming in contact with the superstructure.

Piers Nos. 7 and 9 are pivot piers for supporting the draw girders. They are built without ice-breakers, and are octagonal in plan; they are 34 feet in diameter under the coping when measured at right angles to their sides. Piers Nos. 7 and 9 are backed partly with concrete. They consist of an outside ring of masonry, 4 feet thick under the coping, tied together by two cross wads which are likewise 4 feet in thickness. The open spaces between the masonry are filled with concrete, which, during the work, was kept at a uniform level with the stonework. It was not considered necessary to attach ice-breakers to these piers. No. 9 stands in Black Rock Harbour, where there is no appreciable current; No. 7 is exposed to ice runs, but is sufficiently protected by the rest pier built up stream to support the end of the draw girder when open, and by the crib-work extending between this rest and the pier itself.

Pier No. 10 is semi-circular, or bull-nosed, up stream.

The sides and ends of all the piers, excepting the ice-breakers, are built with a batter of 1 in 24. In Piers Nos. 4, 5 and 6, an offset was made in the masonry, at an elevation of 90, or, in other words, at the bottom of the ice-breakers. On each side of all quoins or angles a 2-inch margin draft is cut.

Piers Nos. 6, 8 and 10, upon which the ends of the draw girders rest, are built with a recess in width equal to half the breadth of the pier, and 3 feet 2 inches deep for their reception. All the piers in both Bridges, except the pivot piers, are finished with coping 18 inches thick, and projecting 3 inches all round. In Piers Nos. 7 and 9 the coping is 18 inches thick on the outside, and 22½ inches thick in the centre. For about 3 feet back from the outside it is of a uniform thickness of 18 inches, so as to afford a level bed for the roller plate; at the centre there is also a level space, being a circle 5 feet in diameter for the pivot casting of the turn-table to stand upon. The coping of the pivot piers also projects 3 inches.

The faces of ice-breakers, surface of copings, and bottoms and back walls of recesses for ends of draw girders are finely bush-hammered; all the rest of the masonry is rock or quarry-faced ashlar.

All the piers, except the pivots, are finished at an elevation of 120·92. The bed of the centre casting on pivots is at an elevation of 113·60.

Piers Nos. 1, 2 and 3 are 28½ feet long and 7 feet wide under coping; Piers Nos. 4, 5, 6 and 8 are 28½ feet long and 11 feet wide, at same level; and Pier No. 10 is 28½ feet long and 8 feet wide.

The plan of Pier No. 2, as shown in Plate VIII., may be taken as the type of Nos. 1, 3 and 8, in which the ice-breakers start immediately from the concrete.

Plate No. IX., representing details of Pier No. 5, represents also the general form of Piers 4 and 6. The octagon piers, Nos. 7 and 9, are shown in Plate XI.

The form of recess for the ends of the swing girders may be seen by reference to plan of Pier No. 6 in Plate X.

The abutments are rectangular in plan, being 30 feet wide and 40 feet long at Bridge seat level, or at an elevation of 120·92. At this level the breast walls are 6 feet 6 inches thick, and the wing walls are 2½ feet thick: these latter are each supported by two counterforts 4 feet by 2½ feet.

At the back of the Bridge seat, which is 18 inches thick and projects 3 inches beyond the face of the abutment, a ballast or retaining wall, 2 feet high, is built. The wing walls above the Bridge seat are surmounted by parapets 3½ feet high, exclusive of coping, and 2 feet thick. The coping is beveled and is 9 inches thick in the middle; it projects 3 inches on each side of the parapets.

The plan of Abutment No. 2 is shown on Plate VII.

Abutments Nos. 1, 2 and 4 are counterparts of each other, except in the height. The general plan had to be modified a little to suit Abutment No. 3, owing to the end of the draw girder resting upon it. It is represented in Plate XII. All the masonry in the abutments is quarry or rock-faced, except the tops of the copings, the upper sides of the Bridge seats, and the front and top of the ballast walls, which are finely bush-hammered. The angles have the usual 2-inch margin drafts to plumb by.

A portion of the stone used for the subaqueous masonry was obtained from a quarry near the village of Bertie, about seven miles from the Bridge. It is a hard, compact blue limestone, very heavy, and exceedingly difficult to work. Fortunately no dressing was required for the beds, as the strata were perfectly parallel and without twist or distortion. The stone was quarried with plug and feather, and therefore, with proper care could be taken out almost exactly of the shape and dimensions needed. The courses vary from 14 inches to 3 feet in thickness.

For the masonry above water nearly all the stone was brought from Georgetown on the line of the Grand Trunk Railway, 29 miles west of Toronto and 174 miles from the Bridge. It is a close grained, solid freestone, light in colour, with occasionally dark lines running through it, indicating the presence of iron. This stone has been largely used on some parts of the Grand Trunk Railway, and has been found to be a most desirable and durable material. The Credit Viaduct, the most important structure on the Western Division of the Road, was built of it, and after standing for nearly 20 years, the material manifests no symptoms of disintegration. In fact it seems to have hardened and improved with age. Courses from 14 to 30 inches in thickness were obtained from the Georgetown quarries.

A small quantity of stone was got about 5 miles from Acton (a station 8 miles west of Georgetown). This was of exactly the same quality as the Georgetown stone, but was free from discolouration by iron.

A few hundred yards of stone were also brought from the Berea quarries, near Cleveland, Ohio. This stone harmonized in colour and composition with that which was procured at Georgetown and Acton.

By the specifications the courses were allowed to range in thickness from 12 to 24 inches, but as it was found when the quarries were properly opened up that very large material could be procured, the bottom courses were made in several instances nearly 3 feet thick, and no course less than 14 inches in thickness was used. For the sake of appearance, the thinner courses were always kept near the top. The top and bottom surface of every face stone are dressed the full size of the stone and the heading points were cut back square 2 feet from the face. The backing consists of heavy uncut stone, scobbled so as to fit as nearly as practicable the places intended for them. All interstices were carefully packed. Every stone was laid in a full bed of mortar, and each course is thoroughly grouted.

In building the piers all the stones composing the ice-breakers, and also the quoins at the back ends of the piers, are clamped and doweled together. The mode of doing this is shewn in detail on Plate No. X.

It was originally intended to build the masonry up to high water with cement, and above that with common lime, but shortly after the work was begun it was determined to use cement throughout. The quantities of cement and sand were one part of the former and two of the latter. It was found that these proportions produced a mortar that set as hard as the stone itself. The cement was obtained at Akron, near Buffalo. It was made imperative that it should always be brought to the work in barrels and not in bulk, as, if stored in the latter form, it deteriorated in quality.

For the concrete a much larger proportion of cement was used, as it was most desirable that it should set quickly. By the specification, which was closely followed, the concrete was to consist of 1 cubic yard of lime or sandstone broken to go through a 2½-inch ring and screened, 1¾ barrels of cement, and an equal quantity of clear sharp sand. The stone was broken by a Blake Stone-Crusher, worked by steam power.

All the materials for the concrete were loaded in proper proportions, but unmixed, on to a scow, and were taken down to the Pier.

The mode of mixing was to cover a space carefully measured out on the bottom of the scow, to a depth of 6 inches, with broken stone. A convenient size was 9 feet by 6 feet, as this area, covered with 6 inches of stone, contained exactly a yard. The proper quantity of cement and sand were then mixed and spread evenly over the broken material; water was then thrown on, and the whole mass turned over as rapidly as possible with shovels until the materials were properly incorporated and wheeled into the caisson.

As no scaffolding or false works of any kind could be erected in the River, by reason of the great depth of water and force of current, all the materials for the masonry had to be delivered in barges laid alongside the piers. The two largest of these barges were provided with horse derricks capable of lifting with safety 5 tons each. These were used for hoisting the stone into the caissons while they were afloat. After the caisson was fairly grounded, a traveller—the plans of which are shown in Plate XIX.—was erected upon it, by means of which all the subsequent hoisting and setting were done.

The ice-breakers of Piers Nos. 2, 3, 4, 5, 6 and 8 are covered from the bottom to a height of 4 feet above low water line with wrought iron plating half-an-inch thick. This covering is fastened to the masonry by fixed bolts with countersunk heads. The nose of the ice-breaker above the armour is protected by a 4″ × 4″ × ½″ angle iron.

The first stone of the Bridge was laid on the 13th August, 1870, in Pier No. 1, and the last was laid in Pier No. 4 on the 4th October, 1873.

CHAPTER VI.

SUPERSTRUCTURE, AND MODE OF RAISING IT.

The truss chosen for the superstructure of the International Bridge was the Linville or Pratt, wholly constructed of iron. The considerations which led to its selection were the correct theoretical principles involved in the arrangements of its parts, and the fact that in practice it had been found to combine all the desiderata of economy in construction as well as of durability. There are, of course, many other good forms of truss in use—each of which has its advocates; but perhaps, on the whole, there is none which has given more general satisfaction than the "Pratt," particularly since the invention of the Phœnix wrought iron column has placed within the reach of the Engineer a combination of iron possessing great strength to resist a strain of compression with the least expenditure of material. The theoretical merits of the truss are—1st, The lines of strains are so clearly defined and easily traced that each member can be accurately proportioned to the duty it has to perform. 2nd, The strains of compression and tension are so arranged that the former are always either vertical or horizontal, with the exception of the end posts. 3rd, The height of the truss, and the double system of triangulation of which it consists, enable a very light web-like arrangement to be adopted, while the great height of the truss reduces the thrust on the top chord and the tension on the lower one, whereby a smaller quantity of iron is required for their construction. A very erroneous opinion is held by many who are unacquainted with the principles of bridge building, that a light truss is necessarily a weak one and that a heavy one must be strong. This arises from overlooking the fact that it is only the material which actually does the work that gives strength to the structure, and that all superfluous metal is dead weight, and consequently a source of weakness. Not only is the Pratt truss correct in principle, but its practical construction, as carried out by the Phœnixville Company, secures the greatest possible economy consistent with thorough efficiency and durability. The details have been simplified and improved. The general arrangement of the parts of the Pratt truss being familiar to Engineers and to others who take an interest in iron bridges, the description of the superstructure of the International Bridge will be brief, and principally confined to those details in which it differs somewhat from bridges of the same type. And as the details and connections of the various parts of the fixed spans are alike in design and differ only in their dimensions, a description of the longest fixed span of 248 feet will be sufficient.

The trusses are divided into nineteen panels: their height is 26 feet, which height, for the sake of uniformity, is maintained in all the other spans, whether fixed or movable, except in the main swing, where it is increased to 36 feet in the centre. The top chords and both end and interior posts consist of Phœnix wrought iron columns. The top chord pieces and end posts are composed of eight sections, the interior column of four only. The end columns have a rake or inclination towards the centre of the truss equal to the width of one panel. They therefore slope at an angle of about 63°; the top chord is made up of 17 lengths, that is to say, 1 for each panel between the inclined end posts. The segments or lengths are connected by means of short castings with circular tenons fitting accurately into the interior (hollow) of the chords. The top chord increases in weight from the ends towards the centre of the truss. The interior diameter of each length is the same, but the segments composing them vary in thickness. The lower chords are made up of links. At the end of each truss only two links are used; in the middle of the span there are eight. These links are equal in length to the panel widths. The main tension rods and the counter braces have a run of two panels, and are consequently inclined at an angle of 45°, which, taking the truss altogether, is the most favourable slope, as the maximum of strength is obtained with the minimum of material. The former, that is to say, the main tension bars are not adjustable; the latter, the counter braces, can be regulated as to length by union screws, by means of which any desirable strain may be thrown on the truss, and the vibration caused by rolling loads reduced. All the connections of the vertical trusses are made by means of pins. The floor beams are in pairs; they are 15 inches deep, with top and bottom flanges 5 inches wide, giving a breadth of 10 inches for the support of the longitudinal stringers. These floor beams are suspended from the trusses by 4 wrought iron loops—2 at each end of the beams. The horizontal lateral braces, required to give rigidity to the floor of the Bridge, are placed between and are secured to the floor beams. At the top the trusses are kept apart by light Phœnix columns extending horizontally between the corresponding joint boxes connecting the lengths of the top chords, and lateral bracing is also inserted between them to maintain the top in position. These braces are connected with the top chords by means of wrought iron loops or stirrups. All the horizontal braces are secured to their attachments at the ends with screw connections, so as to be adjustable; the upright trusses are kept in a vertical position by angle braces at the top, connected with the perpendicular posts of the side trusses and the horizontal straining tubes, which are used to keep the top chords of the two trusses apart. From the above description, it will be seen that each span consists of 4 trusses—

two vertical to carry the whole static weight of the Bridge together with the rolling load, and two horizontal to resist the force of winds and to prevent oscillation or side motion. The trusses rest on cast iron bed plates bolted to the masonry; one end of the truss rests directly on the bed plate and is immovable, the other bears upon rollers so as to admit of the expansion and contraction of the metal in the trusses.

The flooring of the Bridge is composed of four longitudinal stringers with cross ties laid on them. The main or permanent way stringers consist of two pieces, each 8″ by 18″, laid side by side, with a space of about an inch between them. The outside stringers are single, and are 5″ by 18″. The cross ties are 6″ by 12″ and are laid one foot apart. Outside of each rail, and at a uniform distance of eight inches from it, an oak guard piece 6″ by 6″ is bolted to the floor to protect the truss in case of engine or car running off. The most important departure from the ordinary practice of construction was the substitution of wrought for cast iron in the fixed spans, wherever the change could be made with advantage. In a majority of the Pratt or Linville Bridges built prior to 1870 cast iron was used for the upper chords, and in some of them the posts were of the same material. In the International Bridge, Phœnix wrought iron columns have been employed for every member in compression, cast iron being only used for the bed plates on the masonry, for the pedestals of the end and vertical columns, and for the joint blocks of the top chord. From the above description and examination of the drawings, it will be apparent that the quantity of cast iron has been reduced to the smallest amount, and wherever used it is in such a form as to avoid even a possibility of its failing to perform the duty assigned to it. The main tension rods and lower chord links are composed of flat bars, with eyes at each end for the reception of the pins by means of which the connections are made. These tension rods and chord links are formed without a weld. The ends which require to be enlarged for the eyes are upset by hydraulic pressure and the eye is bored out of the solid metal. All the pins are accurately turned. No wrought iron bar having an error of over 1-64th of an inch between the centres of the pinholes is allowed to be used, and in no case was an error of over 1-100th of the diameter of pin or hole permitted to pass. All the screw bars had their ends enlarged to such an extent that the full section was preserved when the threads were cut. The abutting joints in the top chords, in fact all such joints in every part of the Bridge, were accurately planed or turned.

In the swing girders the top and bottom chords are composed of plates riveted together. The use of links in the lower chords of these girders was, of course, inadmissible.

The tension rods, instead of having an eye at each end, have one only at the lower end; the upper ends pass through the top chord, and are formed as screw bars so as to allow of the truss being accurately adjusted by tightening or loosening the nuts at the ends of the bars.

The turn tables are of a pattern designed at the Phœnixville Works, and are shown in detail on Plate No. 16.

In the construction of these tables a novelty is introduced in planing the cast iron bed plates, on which the friction rollers travel. The under surface of the heavy castings above the rollers was also planed. So accurately are these top and bottom circles fitted, that although the joints of the segments composing them can be seen, they cannot be discovered by passing the hand over them on the planed surfaces. The turn tables are made adjustable, so that the whole weight of the Bridge can be thrown singly either on to the centre piers or on to the friction rollers. By throwing it wholly on to the former the Bridge can be made to turn very easily, but not so steadily as when the rollers carry a portion of the weight. The machinery for turning the Bridge is worked by steam power, although provision is made for turning by hand. The engines used on the swings are made by Wilbraham and Bros., of Philadelphia. They are double action upright engines with link motion. There are two cylinders 8″ by 12″. The boilers are upright and tubular. The engines and boiler are placed on the level with the floor of the Bridge, in a house outside of one of the girders and immediately above the turn table; on the opposite side of the turn table, and also outside of the other girder, there is a corresponding house, containing coal bunkers and water tank. For supporting the ends of the swing girders when closed, cams are used; these cams are raised and lowered by the same engines that work the turn table, the connections being made by a line of shafting extending from the engines. For the purpose of locking the Bridge when closed, the rails of the permanent way are extended six inches beyond the ends of the swing, and rest in strong cast iron chairs 2½″ deep, bolted to heavy cross timbers on the adjoining fixed spans. These end rails are not spiked down, but are arranged so that the ends which rest in the chairs can be raised 3½ inches, to clear the sides of the chairs when it is necessary to open the Bridge. The raising of the rails is done simultaneously with the lifting of the cams and by the same machinery. A very ingenious indicator is placed in the engine room to show the engineer when the cams and rails are either raised or lowered sufficiently.

It consists of a long vertical screw working into a square nut, which is fitted between two upright guides which prevent the nut from turning. While the machinery is at work, this vertical screw works in such a direction that the nut is carried upwards to a certain point, which when reached shews that the Bridge is unlocked, the cams and rails raised, and ready for opening. The action of the machinery for closing being of course in an opposite direction from that required for raising the cams, the motion of the nut is downwards to a point near the bottom of the guides, which indicates that the cams and rails are down, the swing closed, and the Bridge ready for the passage of trains.

In the earlier swing bridges of large dimensions which were built for railway traffic, the trusses were so adjusted that, when closed and before being locked, their ends were exactly at the proper level; that is to say, that the surface of the rails at the ends of the drawbridge corresponded exactly with the rails at the adjoining ends of the fixed spans. In adjusting the swing girders in this way, the very important fact was overlooked that when only one half the girder is loaded the deflection in this half has the effect of throwing such a strain on the top chord that the other end of the girder has a tendency to rise. The lift in some cases amounted to nearly ¾ of an inch. To counteract this, the expedient was adopted in the International Bridge of adjusting the ends of the swing girders in such a way that when closed, and before the cams were lowered, they should be about ⅞" below the level of the fixed spans. The lowering of the cams raised the ends of the girders to the proper level. This plan answered perfectly, and now no vertical movement takes place at the ends of the swing girders under the passage of the heaviest trains.

The iron used in the construction of the Bridge was of the toughest and best kind manufactured, and was required to come up fully to the following Phœnixville tests, viz.:—

Ultimate strength tensile strain, 55,000 to 60,000 lbs. per square inch, with no permanent set at 25,000 to 30,000 lbs.

Reduction of area at breaking point average, 25 per cent.

Elongation of area at breaking point average, 15 per cent.

Cold bend without signs of fracture, from 90° to 180°.

The manufacture of the various members of the Bridge was all carried on under inspection of an officer of the Bridge Company, resident at Phœnixville.*

For the main swing the static load was assumed to be......	14,430 lbs.
Rolling load...	17,344 "
Total	31,774 lbs.

The lengths of this truss from centre to centre of end Piers is 358 feet.

Width of panels twelve and a half feet each, except the two centre panels which are only twelve feet.

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* For calculations of strains in spans of 248 and 197 feet, refer to Plate No. XVIII.

Height of truss, 26 feet at each end and 36 feet in the middle.

For the tensile and compressive strains practically the same factor of safety was used as for fixed spans.

A comparison of the above mentioned working strains with the tests which the best Phœnixville iron is warranted to stand, will show very clearly that the factor of safety used in determining the dimensions of the various members of the trusses was certainly a high one.

With regard to the mode of computing the strains, it has not been deemed desirable to give it in detail, as it is perfectly familiar to every Engineer.

No serious difficulty was anticipated or experienced in raising the superstructure of the Bridge over Black Rock Harbour, of Spans Nos. 1 and 7, nor of the swing girder in the Bridge over the Niagara River. A common staging, resting on piles or directly on the rock in the bottom of the River, was used. The only danger apprehended was from the ice, when the spans of the main swing were being built. These were begun in September, 1872, and were not finished until the 3rd January following, On the 12th December a very heavy run of ice occurred, which caused some uneasiness while it lasted, but fortunately no damage was done. The best mode of setting up Spans Nos. 2, 3, 4, 5 and 6, was, however, a matter of anxious consideration. It was impossible to drive piles owing to the rocky bottom in Spans Nos. 2 and 3, and to the great depth of water and velocity of current in Spans Nos. 4, 5 and 6. Several plans were discussed and rejected as impracticable. The idea of a floating staging was the one which seemed to promise best results. It was therefore determined to test it by actual experiment in Span No. 2. The plan answered beyond the expectations of the most sanguine, and was consequently adopted in the erection of all the deep water spans.

The floating staging consisted of three distinct parts, viz., the pontoons for the support of the staging; the lower staging, which extended no higher than the under side of the iron floor beams of the permanent superstructure; and the upper staging.

The pontoons—of which five were used for the 197 feet spans and six for the 248 feet—were 55 feet long from stem to stern, 17 feet wide, and 10 feet high. They were rectangular at the back end and pointed at the bow, being of the same general form as the water-tight caissons used for the piers.

Each pontoon was divided into two parts by a partition running transversely, so that water could be let into one end only. At the bottom of this partition a common hinged valve was placed to allow the water to run from one compartment to the other when necessary. Each pontoon was also provided with two hydrants near the bottom—one at each end communicating with the water outside.

By means of these the water could be let in at pleasure. These pontoons were placed equidistant from each other, and the spaces between them and the piers were one-half of the width of opening between any two pontoons. Between the end pontoons and the piers, rafts were placed to steady and prevent them from sheering.

Each pontoon was provided with a tow post and four snubbing posts—two on each side; the use of the latter was to afford a bearing at the back of the sills of the lower staging and to prevent the pontoon being drawn from under it.

Each pontoon was held by one cable. All the cables were gathered together about 500 feet above the Bridge, and were made fast to a single pontoon—a camel, which was kept in place by three heavy anchors dropped about 500 feet up the River.

The stagings were of a simple but very strong character, and were of the form shown on Plate No. XVII. They consisted of two systems of framing, wholly separate and distinct from each other, the upper one merely resting on the lower one, but not fastened to it. On the top of the upper staging common railway bars were laid to form a track to carry a powerful traveller used for hoisting the various parts of the iron superstructure. This traveller is shown in the drawings. In building the staging for Span No. 2, the pontoons were floated singly between Piers 2 and 3, and the upper works were then erected. While the iron superstructure was being put up, the whole staging was kept about 8 or 10 feet up stream, so as to make provision against the anchors dragging during a severe storm.

The top of the lower staging was kept about a foot above the tops of the piers, to avoid the danger of the superstructure landing in an unfinished state on the masonry by a fall of water in the River. The determination of a safe height for the staging was nearly a matter of certainty with the data furnished by the daily observations of the rise and fall of the River, taken over a long period.

In building the iron work it was necessary to support the pedestals or foot blocks of the sloping end columns. This was done by blocking up between the under side of the first pair of lower chord links, and the wooden cross beam or sill at the bottom of first, bent at each end of the top staging. Between the pedestals at each end a straining piece was inserted of such a length that they were kept exactly 20 feet apart from centre to centre. The pedestals were also bound together firmly so that they could not separate more than 20 feet. When the iron superstructure was ready for being placed on the masonry, the pontoons were lowered down stream to the proper position. Blocks and tackle were then fastened to each of the top corners of the lower staging. These blocks upon the down stream corners were connected with the up stream ends of the piers, while those on the upper corner were connected with the lower ends of the piers, This tackling was used to steady the ends of the staging and to bring the pedestals exactly over the bed plates.

Before sinking the pontoons, the upper staging was secured to the iron work in such a way that it would remain suspended when the pontoons were lowered sufficiently to admit of the bottom staging being floated away from under the iron superstructure. This was done to avoid the danger of lifting the iron work by the rise of water above the masonry. As soon as Span No. 2 was in position, the pontoons, with the bottom staging remaining on them undisturbed, were lowered down stream about 100 feet.

Four large tugs were then attached to the camel pontoon, to which the cables of the ordinary pontoons were fastened, and the whole system was moved down stream round the east side of Pier No. 3 and back into the space between Piers Nos. 2 and 3 to receive the upper staging, which was meanwhile being taken down from Span No. 2. As Spans Nos. 4, 5 and 6 could not be proceeded with when Span No. 3 was finished, both stagings were taken down, and, together with the pontoons, were stored away for future use.

The first span for which it was afterwards required was No. 6. In the erection of the superstructure of this span, the same course was followed as in Nos. 2 and 3. When the iron work was in place, the pontoons, with the lower scaffold, were towed round Pier No. 5 and up the stream to a position above Span No. 3, where they were allowed to remain until Pier No. 4 was completed. Seven powerful tugs were required for this service, owing to the greater length of the span and the additional force of the current in the middle of the river.

When the masonry was finished, the staging was moved into place between Piers Nos. 3 and 4. The operation of moving a structure 240 feet long and 46 feet high exactly into position was one requiring much care.

The method adopted was to place a large anchor directly above the centre Span No. 4, 1,200 feet up stream. The cable attached to this anchor was then carried over and connected with the camel pontoon. The cables of the other two anchors holding this pontoon were then gradually slackened, and the strain allowed to come on to the cable first placed above the centre of Span No. 4. In this way the staging was brought directly above the place intended for it, and all that was then required to be done was to slacken the cables connecting the pontoons supporting the scaffold with the camel. When Span No. 4 was completed, the mode of transferring the pontoons to Span No. 5 was changed. Instead of lowering and hauling them round, they were drawn up stream about 300 feet above the Bridge, and were then moved into place in the same way as they were from their position above Span No. 3

to Span No. 4. The operation of drawing the pontoons up from Span No. 4 was laborious and tedious, particularly in its early stage, when the pontoons were weighted down with water, which could not be pumped out till the staging was quite clear of the iron superstructure. Two tugs were employed in hauling the pontoons up stream on their own cables. Two days were consumed in accomplishing this.

When the six pontoons used in the erection of the 240 feet spans were fully loaded with all the false works and the iron superstructure, their immersion was four feet while that of the camel was about five feet. The suggestion to use a floating scaffold for building the iron work was viewed with considerable doubt. A floating staging for the erection of a rigid structure, which required to be placed with extreme accuracy, was a novelty; but as no other plan seemed to offer such good chances of success, it was decided to try the experiment.

As already stated, it answered the purpose admirably.

In some respects it was decidedly better than an ordinary scaffold built on the bottom. Any irregularity of shape in the staging when afloat was more easily rectified by filling in and pumping out water than it could have been on a fixed one.

The operation of sinking the pontoons to let down the iron work on the masonry was exceedingly simple and thoroughly under control.

The inflow of the water could also be regulated with great ease and exactness, and the iron work lowered at any desired rate.

The time taken from the opening of the hydrants till the iron superstructure was resting safely on the piers was from half to three quarters of an hour. The first piece of iron for the superstructure was raised on the 17th June, 1871, and the last span, No. 5, was lowered into place on the 29th October, 1873.

The Bridge was opened for the passage of trains by Mr. Richard Potter, President of the Grand Trunk Railway, and by Mr. C. J. Brydges, President of the International Bridge Company, on the third day of November, 1873.

CHAPTER VII.

ICE.

Reference has already been made to the large quantities of ice which pass down the Niagara River, and to predictions as to the destructive force it would exert on the piers.

The designers of the structure had full confidence in the stability of the masonry in the piers; but, as a matter of interest, and by way of further investigating the question of the force of moving masses of ice, it was determined to make a series of experiments upon the crushing strain of ice, and to deduce from them, by calculation, the forces which the masonry would have to withstand. From a number of carefully conducted trials, made at the Toronto Rolling Mills during the month of February, 1871, it was found that the crushing strain of ice is 208·33 lbs. per square inch. The experiments were made with blocks containing exactly a cubic foot each, and were sufficiently numerous for a thoroughly trustworthy inference being drawn from them.

However much opinions may differ as to the action of ice against an immovable body, there is one fact that must be acknowledged by all, which is, that the force exerted cannot be greater than is sufficient to crush or disintegrate the ice which comes in contact with that body.

Assuming this to be correct, we have the following data from which to calculate the strains to which the piers will be exposed from ice:—

1. The thickness of the ice.
2. The force required to crush it per square inch.
3. The area of masonry exposed to its action.
4. The velocity of the current.

As Piers Nos. 1, 2 and 3 are much smaller than the others, and consequently less able to resist a strain, the results of the calculations made for them only will be given.

PIER No. 1.

Thickness of ice, 3 feet.

Area exposed, 36·32 square feet.

Current, 4 miles an hour; in reality, it is only 2½ miles.

The horizontal pressure necessary to set this pier in motion down stream bodily is .... 1,222,500 lbs.

The horizontal pressure necessary to set the pier in motion sideways bodily is—

Towards the middle of the stream	937,600 lbs.
Towards the shore	1,474,700 lbs.

If the pressure is applied at a point 20 feet from the top, the pressure required to overturn it is—

Towards the middle of the stream	1,166,218 lbs.
Towards the shore	1,338,315 lbs.
The pressure due to the crushing strain of ice is	688,080 lbs.
Quasi fluid resistance	272 lbs.
Total maximum pressure of ice is	688,352 lbs.

PIER No. 2.

The data for this Pier are the same as for Pier No. 1, excepting of course that it stands in deeper water, and that there is a difference of one or two inches in the width.

The horizontal pressure required to set Pier in motion down stream bodily is	1,413,200 lbs.
To set it in motion sideways towards centre of stream ...	1,191,900 lbs.
To set it in motion towards shore	1,552,400 lbs.

To overturn it sideways by a horizontal pressure applied 20 feet below top—

Towards centre of stream	985,155 lbs.
Towards shore	1,083,450 lbs.
Pressure of ice on Pier in direction of stream is due to crushing strain	725,200 lbs.
Quasi fluid resistance	334 lbs.
Total maximum pressure of ice	725,534 lbs.

PIER No. 3.

Data same as before, except current, which is assumed to be six miles per hour. The height of pier from bottom of river is greater, and the area exposed to ice is 38.26 square feet.

The horizontal pressure necessary to set this pier in motion down stream bodily is	2,204,800 lbs.
Horizontal pressure required to set it bodily in motion sideways towards shore is	2,473,400 lbs.

Horizontal pressure required to set it bodily in motion sideways towards centre of stream is	1,861,500 lbs.
Horizontal pressure required to overturn the pier (applied at 20 feet vertically below top) towards centre of stream is	803,050 lbs.
Horizontal pressure required to overturn the pier (applied at 20 feet vertically below top) towards shore is	969,040 lbs.
Pressure of ice on pier in direction of stream due to crushing strain is	758,800 lbs.
Quasi fluid resistance	738 lbs.
Total maximum pressure of ice is	759,538 lbs.

The reason for calculating the pressure required to overturn the pier applied 20 feet vertically below the top is, that it was supposed that possibly ice might become wedged or packed between two piers, and have a tendency to overturn them sideway.

The height of the piers above water was assumed to be 20 feet, although in reality it is 21 feet, the difference being in favour of stability.

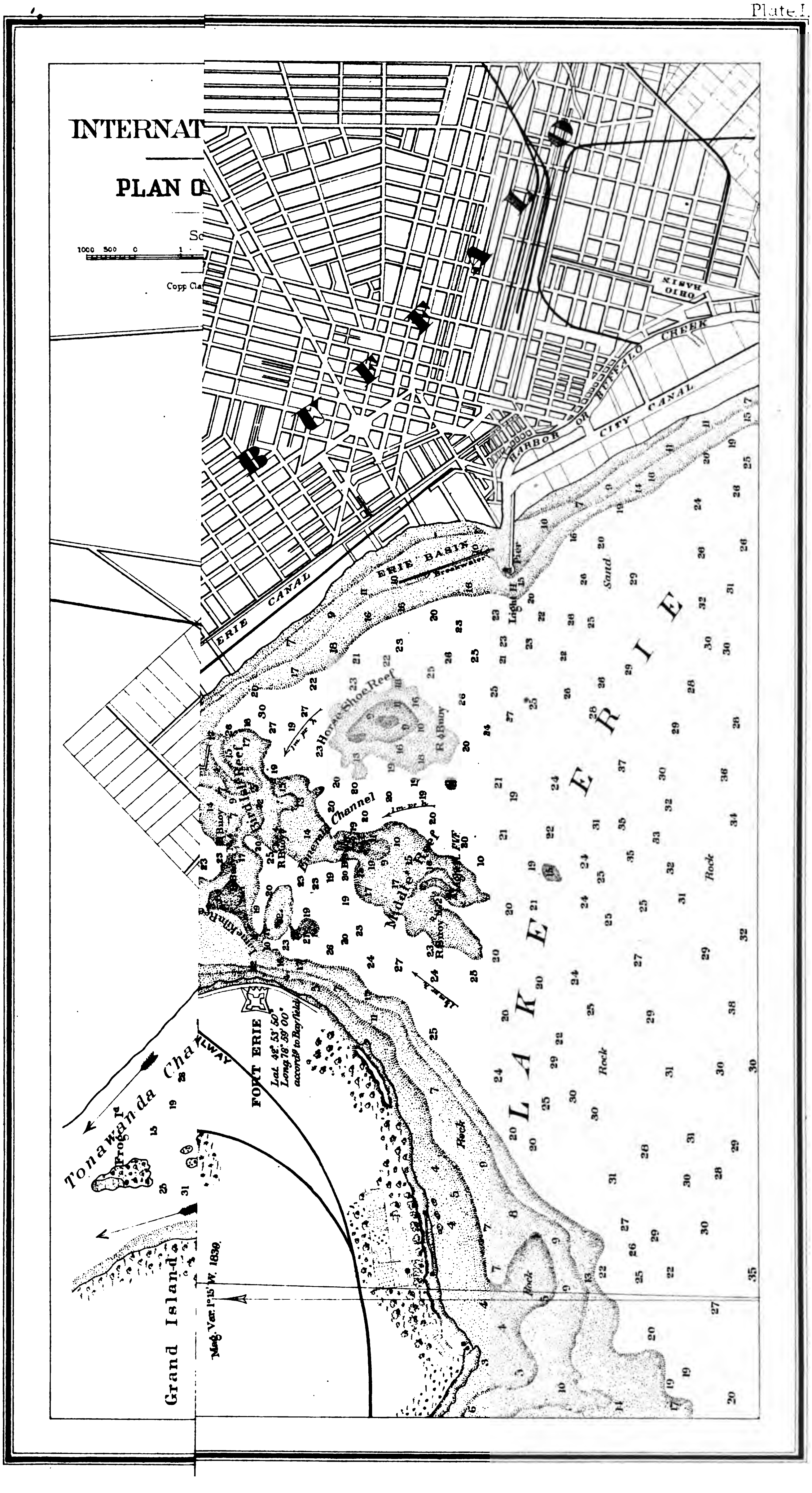
All the calculations made to determine the forces required to move or overturn the piers were made upon the assumption that the piers were standing alone, and without the superstructure resting upon them. The superstructure will add greatly to their stability, not only by its weight but by bracing one pier against another.

Notwithstanding the fact that Piers Nos. 1, 2 and 3 have withstood, without moving, the ice of three winters—two of them having been of unusual severity—and all the other piers except No. 4 were also exposed to the ice of last winter, assertions are still made that although the ice was of extraordinary thickness during the last two winters, yet the Bridge has not been fully tested. It is asserted that during some winters the fields are larger and more numerous, but it is not said they are thicker. The fact is overlooked that if the piers can stand against an ice field three feet in thickness and of sufficient size to bring pressure enough against the pier to crush the ice, they can stand against other fields which are infinitely larger. The size of the field of ice makes no difference whatever so long as there is no increase of thickness. To assert that it does would be as reasonable as to tell a farmer that the draught of his plough is determined by the size of the field he is cultivating.

ERRATA.

Page 20.	For “scour” read “scow,” or barge.
“ 25.	For “C.E., M.A., I.E.C.” read “C.E., M.A.I.C.E.”
“ 50.	For “wads” read “walls.”

Plate I.


INTERNAT
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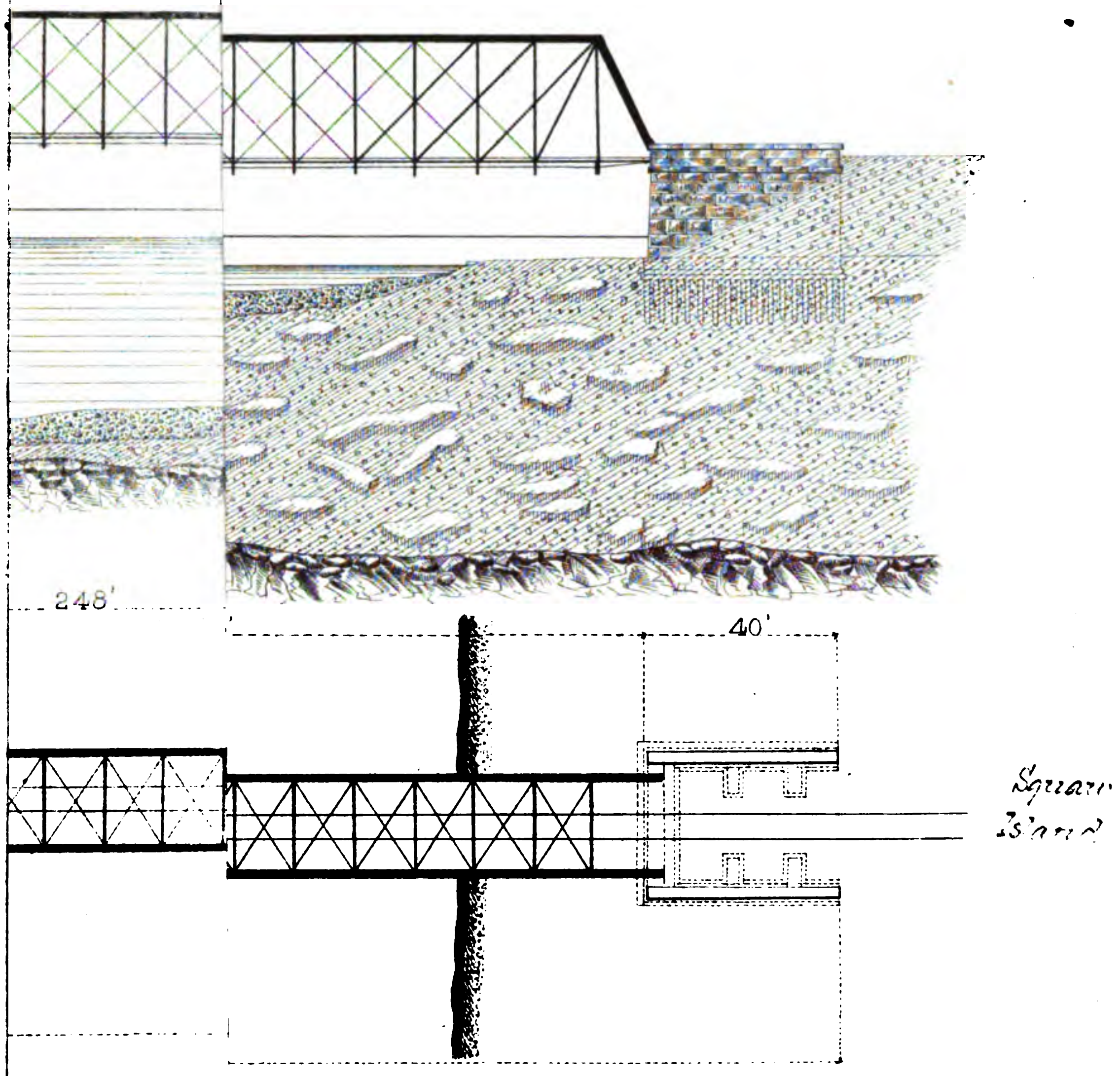
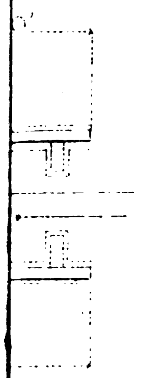
BUFFALO
LAKE ERIE
ERIE CANAL
ERIE BASIN
Breakwater
Light H.
Pier
HARBOR OR CITY CANAL
BUFFALO CREEK
OHIO BASIN
Horse Shoe Reef
Middle Reef
Emerald Channel
Bird Island Reef
R. Buoy
Sand
Rock
FORT ERIE
Lat. 42° 53' 50"
Long. 78° 59' 00"
Tonawanda Cha
Frog I.
Grand Island
Mag. Var. 1° 15' W. 1839
RAILWAY

Plate II.



No. 2 Begun Sept /71
Finished June /72



371
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Plate XV

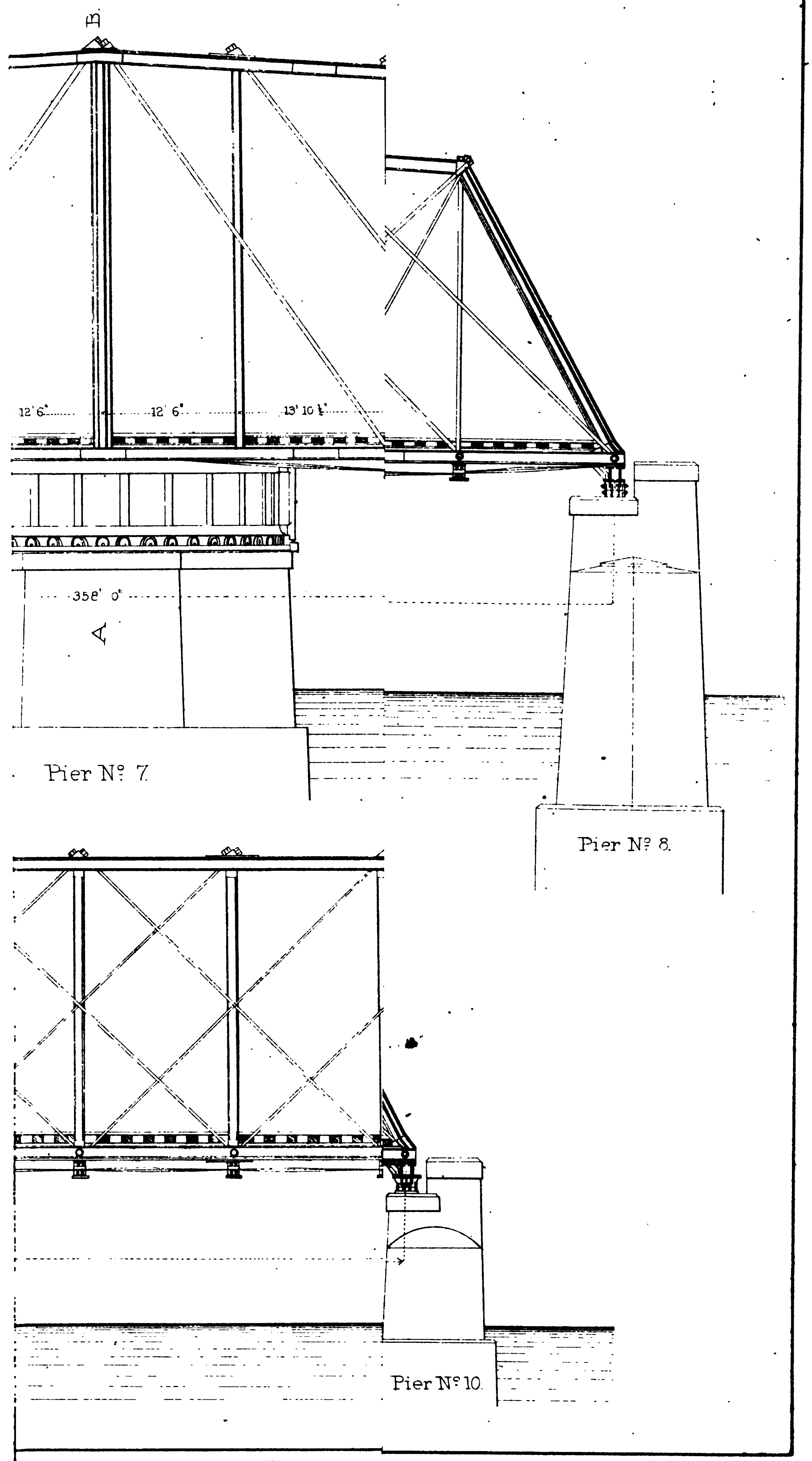
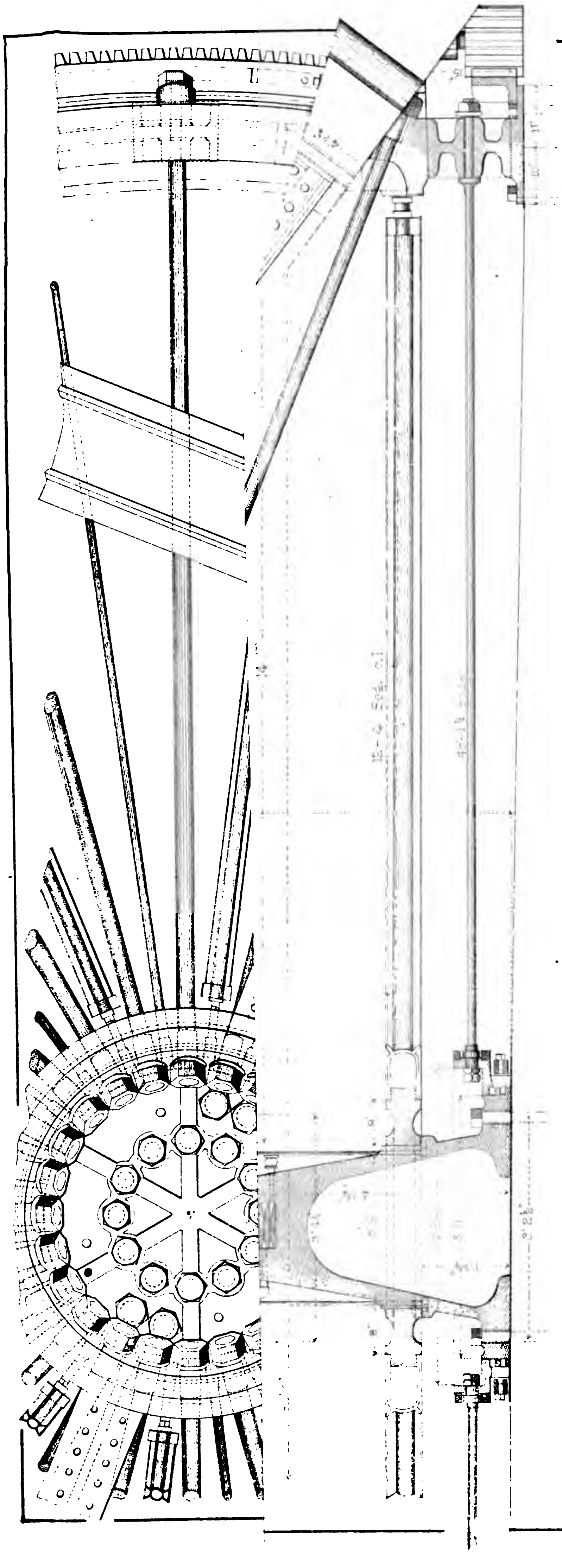
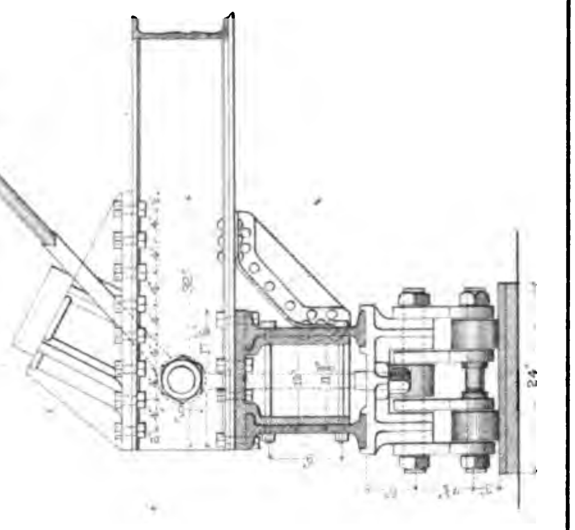
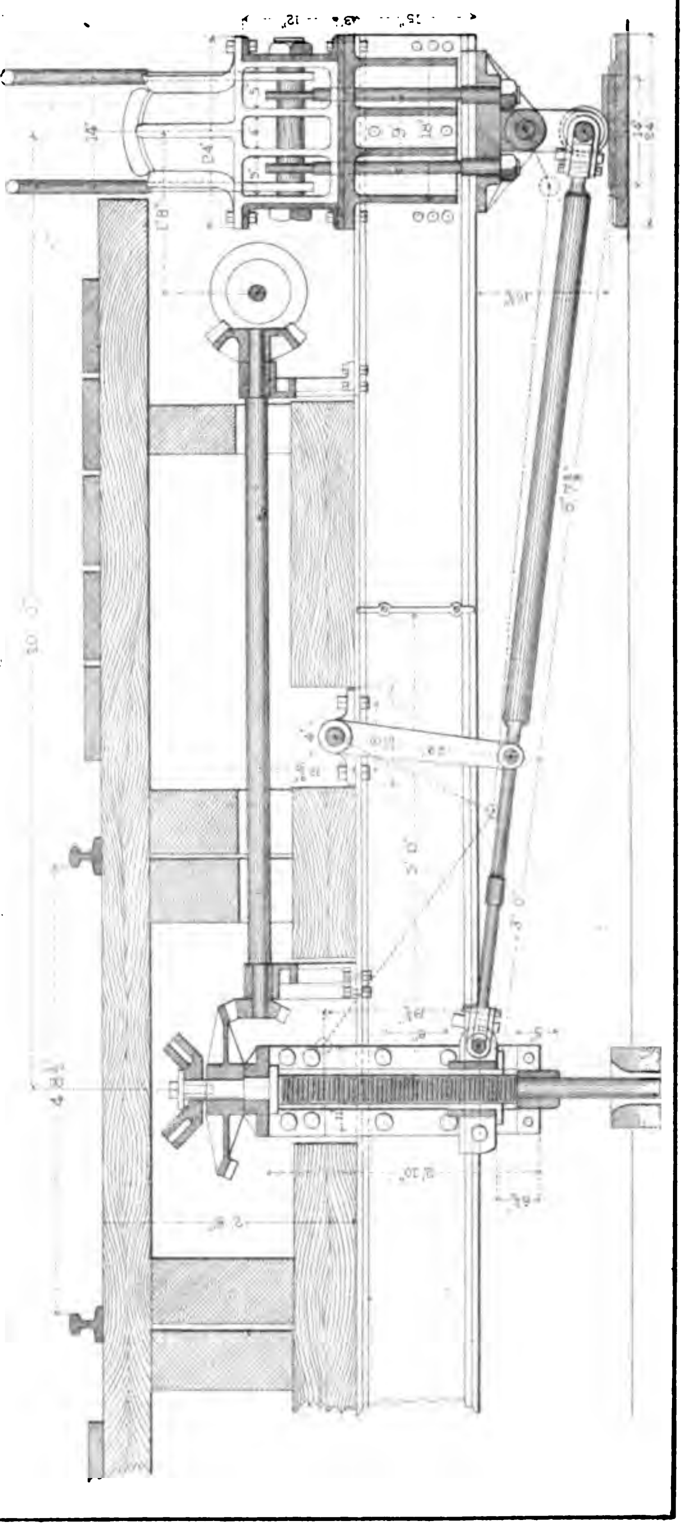


Plate No XVI.

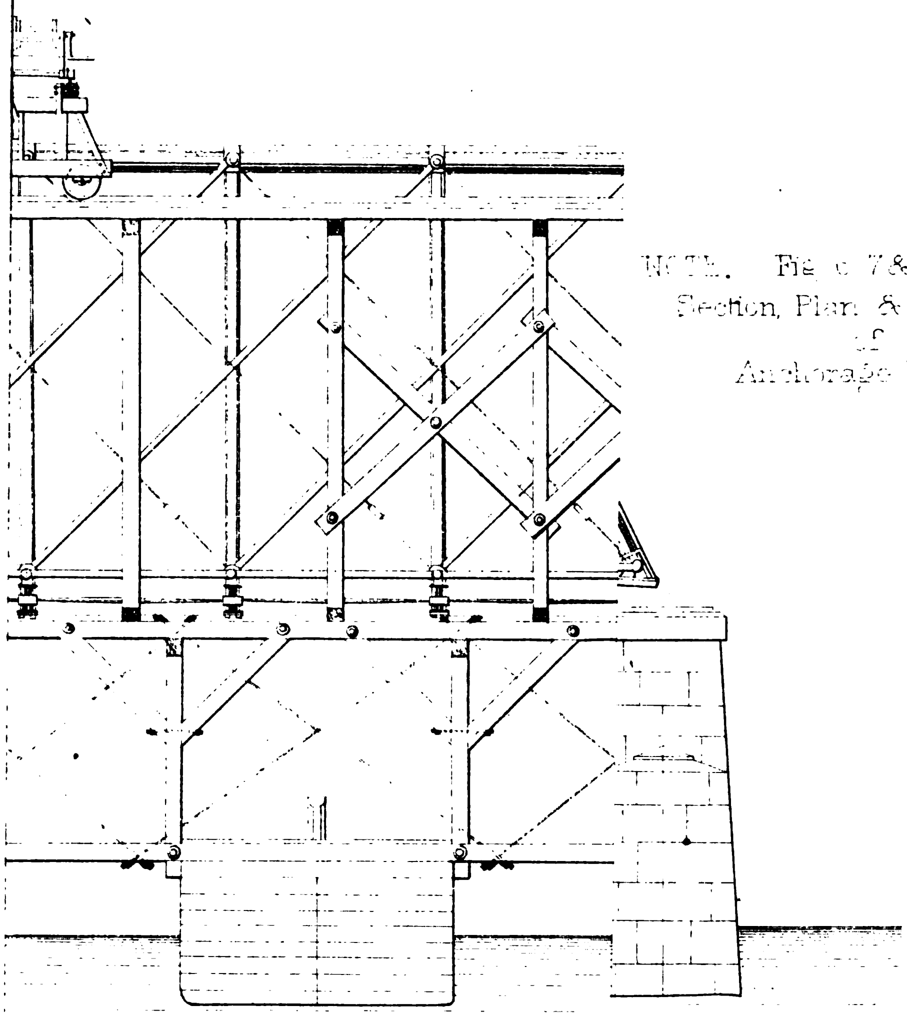




Side View of Locking Gear Fig. 4



Locking Gear in Plan Fig. 3



NOTE. Figs 6, 7 & 8 are Section, Plan & End View of Anchorage Pontoon.

Fig. 6.

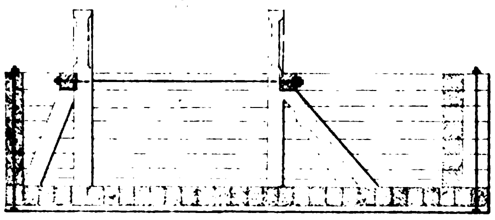


Fig. 7.

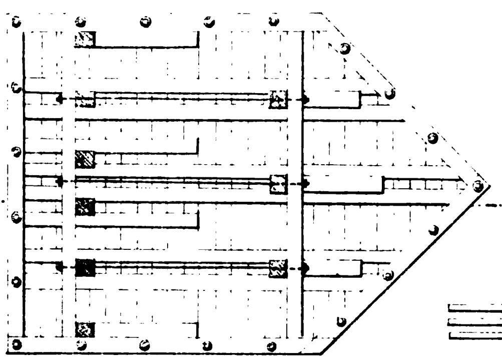
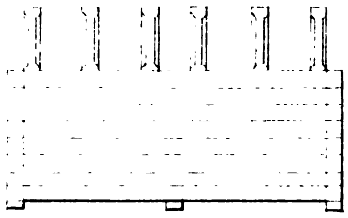
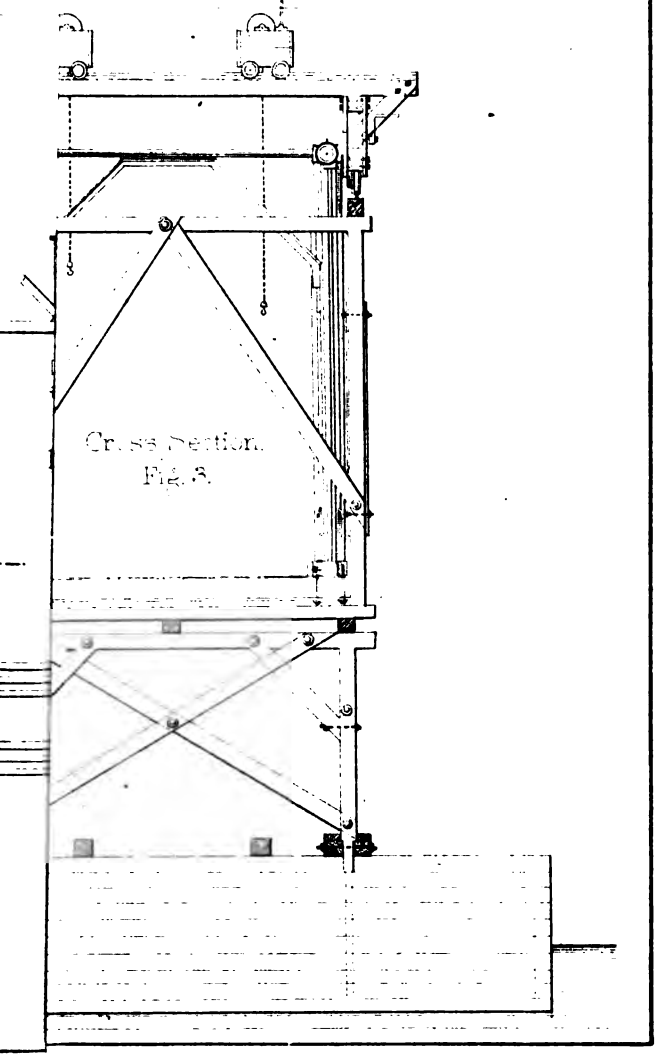
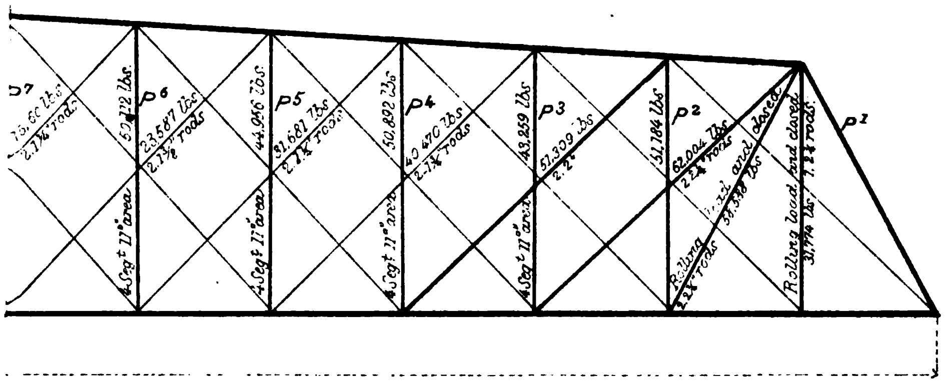


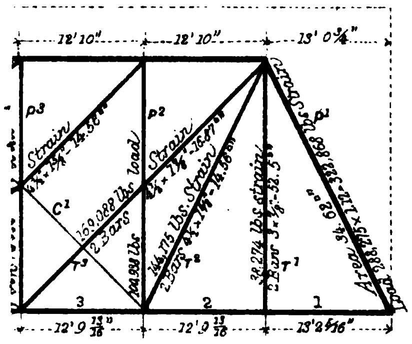
Fig. 5.





Cross Section. Fig. 8.



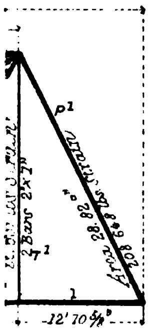


Working Strains.

Compression on Top Chord and end Posts	- 8,800 lbs per Sq. in.
Compression on Interior Posts	- 5,000 , , , ,

These loads bring ¼th of the ultimate strength deduced from Gordon's formula.

Tension on bottom Chord and Ties	- 10,000 lbs. per Sq. in.
Tension on Suspension loops.	- 7,500 , , , ,
Shearing Strain on Pins	- 8,000 , , , ,



Working Strains.

Compression on Top Chord	- 8600 lbs per Sq. in.
Compression on End Posts	- 7240 , , , ,
Compression on Interior Posts	- 4472 , , , ,
Tension on bottom Chord and Ties	- 10,000 , , , „
Tension on Suspension loops	- 8,000 , , , „
Shearing Strain on Pins	- 8,000 , , „ „

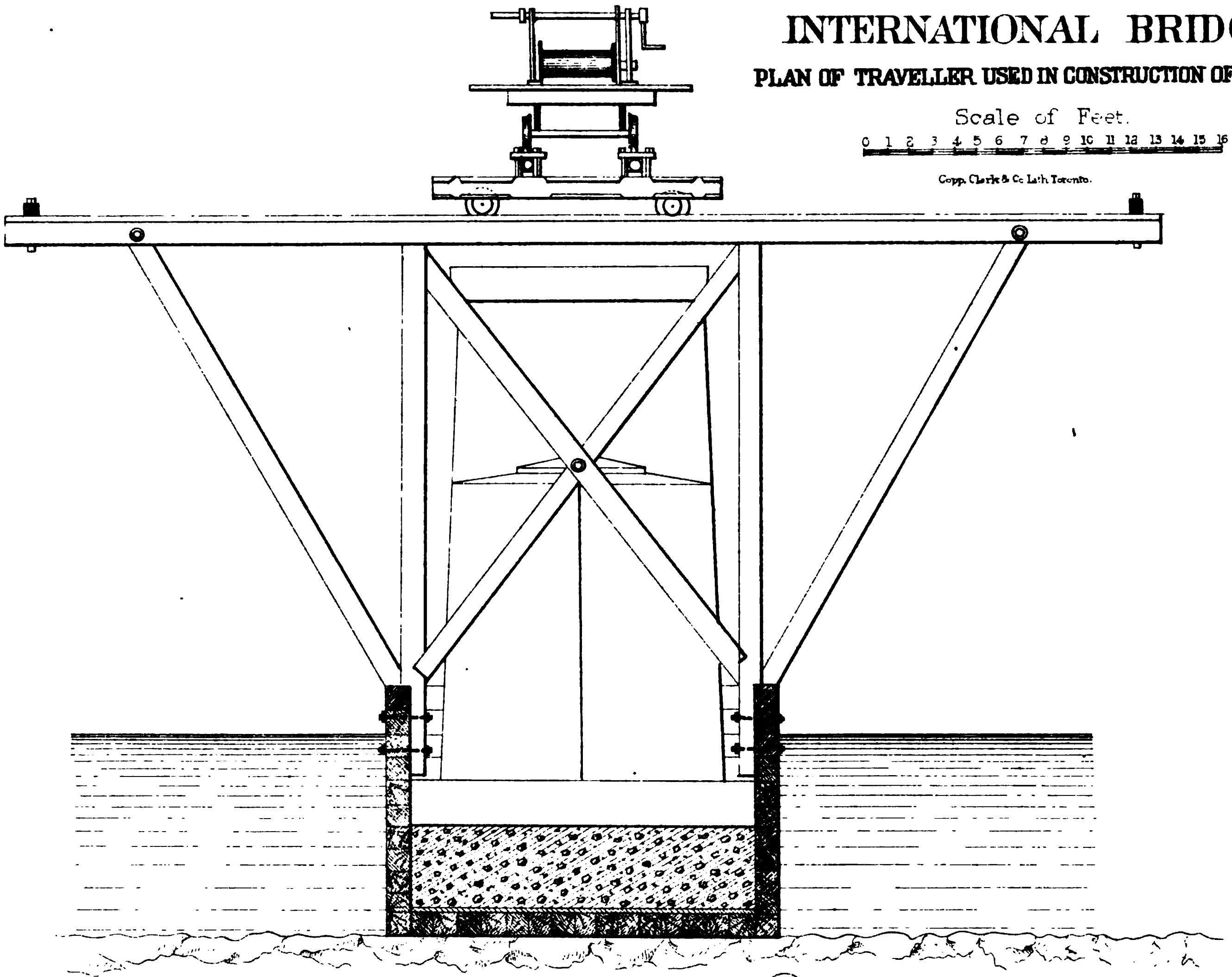
Plate XX.

INTERNATIONAL BRIDGE..

PLAN OF TRAVELLER USED IN CONSTRUCTION OF PIERS.

Scale of Feet.

Copp, Clark & Co Lith Toronto.



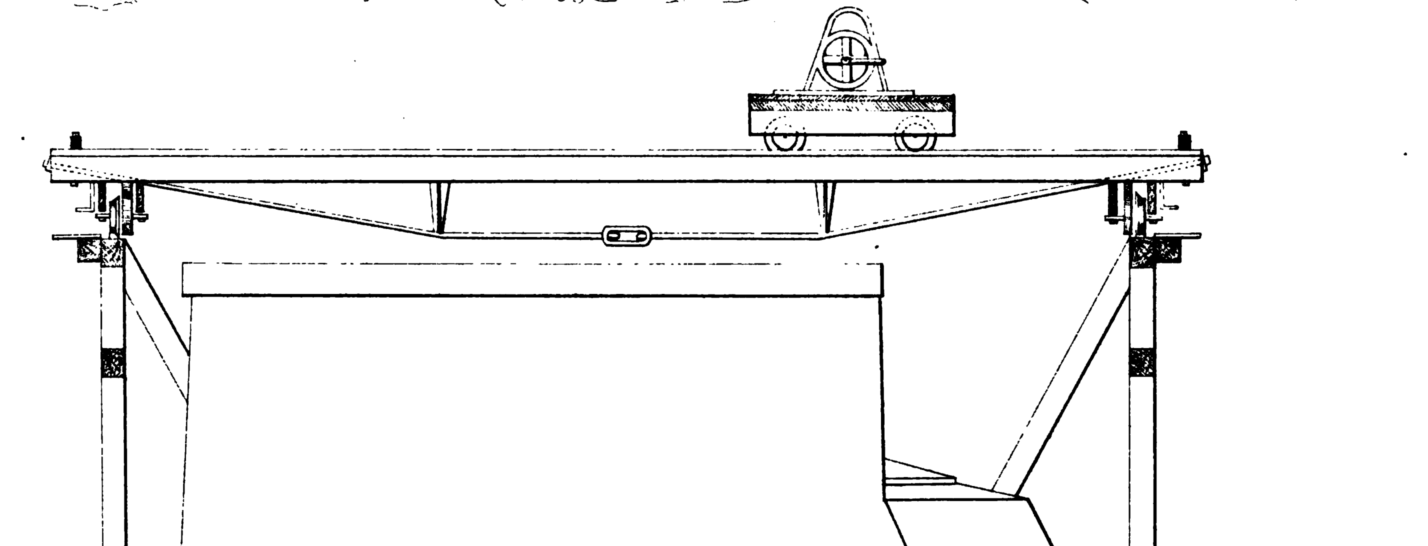
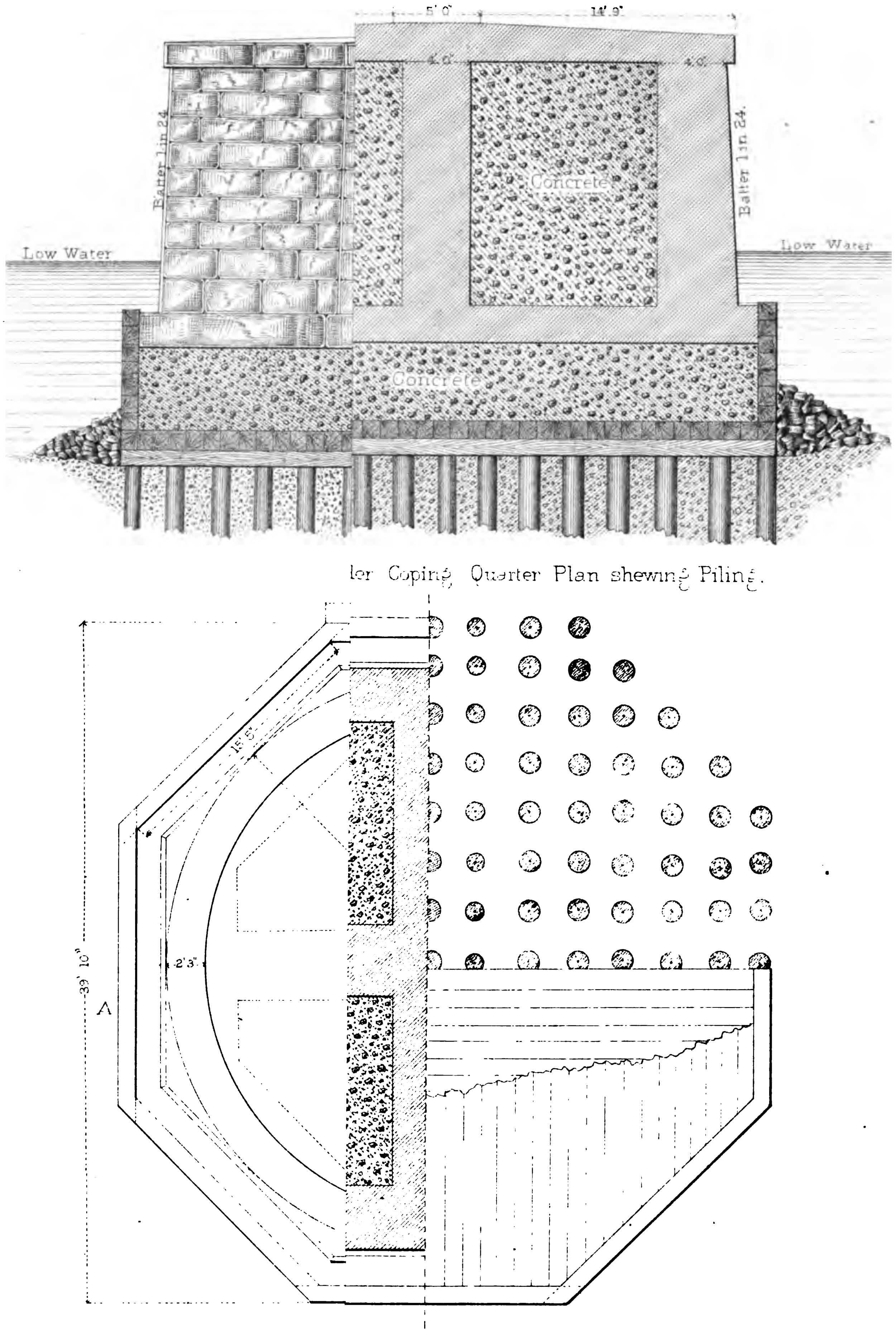


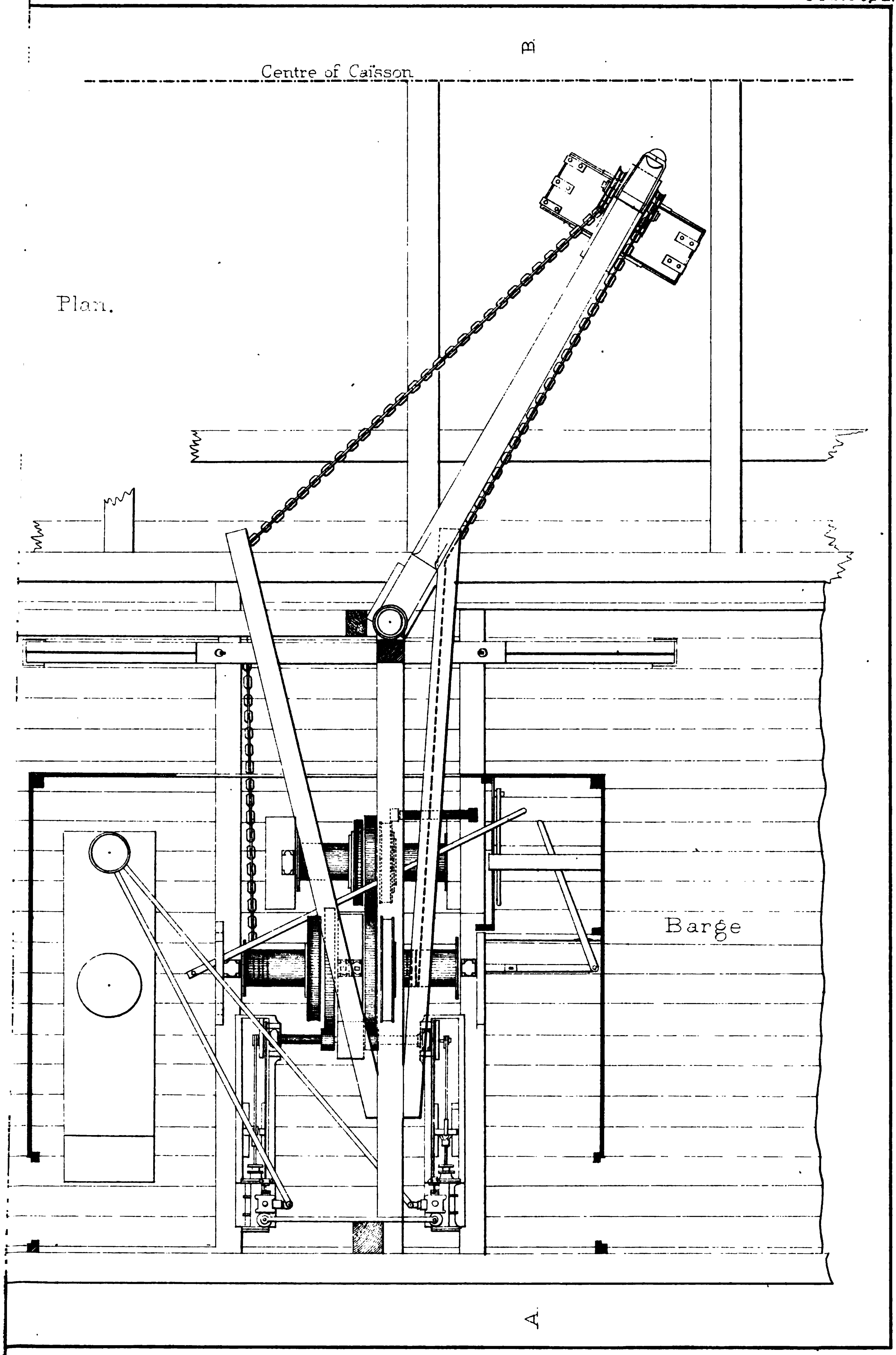
Plate XI



Section thro' A. B.

Quarter Plan shewing Piling.

Quarter Plan shewing Caisson.


B
Centre of Caisson
Plan.
Barge
A

Eng 738.73.3
Description of the international br
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3 2044 092 024 272